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THE LIFE AND SERVICES OF LOUIS PASTEUR.

(*Read Jan. 5, 1923.*)

Pasteur, like Lincoln, is a legendary figure. The son of the simple tanner of Dôle, who was born only a hundred years ago, has become, by common consent, one of the heroes of mankind. His fame is secure. It rests upon no opinions that time can alter, but upon truth which he discovered. This truth we know and judge by its fruits. It has enriched us, relieved our sufferings, and preserved our lives. It has enabled us to see and to understand what was invisible.

In the long history of science no man perhaps has been a greater discoverer; none, assuredly, more exclusively a discoverer. Pasteur, said Gaston Paris, was the very genius of experimentation. To this end each of the traits of his character seems to have contributed; his ardent patriotism, his quiet faith, no less than his love of labor, his sense of duty, and his burning passion for truth. The union of these traits produced no universal genius, but a strong, self-reliant, and virtuous personality, a man at once simple and great.

I.

The history of his life has been well told, and is widely known. For many years it is the characteristically modest story of a French professor. At school in Arbois and later at the Collège de Besançon, Pasteur's faithfulness promised a useful life, rathan than one of high distinction. Later, when he went to the École Normale in Paris, his true abilities began to assert themselves. It is of this period that a famous story, which has long since become traditional, is told. One of his comrades at the school, in discussing Pasteur, found no fault with him but one. He feared that Pasteur might accomplish nothing because he loved insoluble problems. At the École Normale, Pasteur became interested in crystallography, and undertook a series of investigations which within a few months after he had finished his work at the school led to his first great achievement. These researches occupied the earlier years of his productive scientific activity, they brought

him just fame, and led to the foundation of the department of science known as stereo-chemistry.

He was sent in 1848 to Dijon as professor of physics, but fortunately was moved within a few months to Strasbourg as professor of chemistry. Here he completed his researches on the tartaric acids, which began in the crystallographical interest, and extended until they gradually included a very perfect treatment of the whole subject. Among other observations, one is important because it is the connecting link with his later work. He discovered that mould distinguishes between two nearly identical forms of tartaric acid when both are present, selects one for destruction, and thereby reveals a very remarkable specificity. The recognition of this chemical singularity of a microörganism is a clue to a great part of Pasteur's later work.

In 1854 Pasteur found himself at Lille as dean of the Faculty of Sciences. Lille is the center of an industrial region, and here his attention was attracted to the problem of fermentation, the manufacture of alcohol, and the industrial difficulties that were sometimes involved. Thus begins that work which continues without interruption, without logical discontinuity, without experimental discontinuity, throughout the rest of his life. It leads him on from one revolutionary discovery to another.

The first study of fermentation, remarkable as it is and interesting as it is, does not suggest to the uninitiated what is to come; but it deserves to be explained. It was not published until after he had left Lille and returned to Paris as Sous-Directeur of the École Normale. This work on lactic fermentation established with perfect accuracy several propositions. First, that lactic fermentation depends upon the action of a specific organism which is not yeast, and that the organism does not produce butyric acid, but only lactic acid; secondly, that good fermentation in general depends upon the purity and the homogeneity of the culture and upon a nutrient medium suitable to the organism; in the third place, that the nutrient medium must be suitable not only as nutrient material, but also as environment. Thus an acid reaction is favorable to yeast, a neutral reaction to the lactic acid organism. Finally, in a culture where there is more than one organism there is an actual struggle for existence, and in the long run one form is likely to win, to dominate, and to supplant the others. This

struggle for existence may be modified by changing the conditions in the culture medium.

A year after the publication of this work appeared Pasteur's paper on alcoholic fermentation. Here he clearly showed the way toward the preparation of definitely known culture media in which each of the constituents was a pure substance. Into such a medium the organism could be introduced in very minute quantity by inoculation. The work that remained to be done before this could be accomplished with ideal accuracy and certainty was great, but the indications are clear, and there is no doubt about Pasteur's partial realization of the aim.

There followed studies of butyric fermentation, in which the peculiarity of the anaërobic fermentation process was established; studies of putrefaction, in which the occurrence of hydrogen sulphide was noted among the products, as hydrogen had been noted in the butyric fermentation; and then in turn the investigation of the manufacture of vinegar and of the organism involved in the production of vinegar.

At this time Liebig's theory of fermentation, although shaken by Pasteur's work, still had great weight in the minds of men of science. Liebig was one of the greatest of chemists. He had advanced not only pure chemistry, but also biological chemistry and agricultural chemistry. His theory of fermentation was a natural and, at first sight, a proper development of the subject. Lavoisier had made it clear that fermentations are in one sense chemical processes, and can be described as such. The growing knowledge of that mysterious phenomenon, catalysis, in which substances seem to cause chemical reactions through their mere presence without being used up, had attracted great interest among chemists; and it was perhaps inevitable that a theory like Liebig's should have been suggested to explain it. But Liebig's theory suffered from certain disadvantages. In the first place, it was unnecessarily elaborate—that is to say, it went farther than was expedient as a working hypothesis; and in the second place, it did not take account of the phenomenon that Pasteur had seen in his very first experiments and that recurred again and again in all of his studies of fermentation—the specific character of fermentations and the essential difference between fermentation produced by one kind of organism and that produced by another.

Liebig, when he undertook to defend his doctrine, still failed to realize this, and put himself in Pasteur's hands for that reason. Yet Liebig, by retiring within the cell, so to speak, by pointing out that there still remains a question of what it is in yeast that causes alcoholic fermentation, of what it is in the lactic acid organism that causes lactic acid fermentation, showed that much remains to be explained. This question also interested Pasteur's great compatriot, Claude Bernard, a physiologist who had reflected long and seriously on the question of the mechanism of physiological processes. In particular his attention had been called to the problem of what we now call enzymes or soluble ferments, by an observation of Berthelot's. The presence of such substances within the cell seemed to Claude Bernard very probable. Pasteur paid little attention to these more theoretical aspects of the question. Instead he turned his attention to the diseases of wine and beer.

Pasteur next studied the diseases of the silkworm, which at that time threatened the whole silk industry of France. He found that there were two diseases involved, one chronic and the other acute. He made out the organism of the chronic disease, failed to work out clearly and unmistakeably the organisms of the acute disease, and was unable to obtain satisfactory cultures. But he conquered the diseases and saved the situation.

During this period, in the year 1868, he was overtaken by paralysis and his life was despaired of. Yet he was destined still to live for nearly thirty years, and, until near the end, to live with undiminished activity, intelligence, and fruitfulness.

Meanwhile the science of bacteriology was growing. Pasteur had, so to speak, created it. He had formed a school, partly by direct contact with men, partly by setting forth results that others desired to rival. In particular the disease called anthrax had attracted the interest of bacteriologists. The organism had been observed by Rayer and Davaine as early as 1850. Then Davaine had found that it seemed to be always present in sheep dying of anthrax, but he had failed to obtain cultures. Next Koch succeeded in making cultures and observed the spores. The proof of the bacterial cause of anthrax was, indeed, almost at hand. But men are slow to accept new beliefs of a revolutionary character, and, as Duclaux has pointed out, it was

necessary at this moment, and perhaps in this particular case more than any other, to have an investigation so thorough, so unanswerable in every respect, that no one could longer doubt. Pasteur was the one man capable of conducting such an investigation. For years he had worked upon bacteria; he knew their behavior, he knew the methods of experiment, nearly all of which he had invented, and he possessed superb experimental skill.

He proceeded to study the cultures of the anthrax organism, to pass organisms through successive cultures, and to experiment. The results clearly established the specific nature of the disease caused by this particular organism, and proved that it was the organism itself that had to be introduced into the body in order to produce the disease. These investigations and those of chicken cholera led him on to other pathological researches, for at length he began to perceive a phenomenon that he had not suspected before, one which complicated the simple ideas that he had held. This phenomenon was diminution of virulence, a decrease in the power to produce disease, or in the severity of the disease as the organism varied through culture. He also found that he could increase as well as attenuate virulence. And then, with his clear vision of the necessity of turning a discovery into an act, he went on in the direction of vaccination, of rational as distinguished from empirical vaccination; and so he and the rest of the world were led to the knowledge of immunity; and finally his life work was crowned by the famous study of rabies.

It is important not to omit a catalogue of these achievements of Pasteur, because, in the case of Pasteur more than in the case of almost any other man, his work is made up of the sum of the positive facts that he discovered. This is one of the characteristics of the man. Most great investigators have contributed relatively more by way of theory and relatively less by way of discovery than Pasteur. It is essential to go over and catalogue his positive achievements, if only incompletely, in order to appreciate the significance and the peculiar quality of the man.

The facts discovered by Pasteur had created a new science. That new science was using his methods. It was because he had invented these methods that he had discovered the facts; for there is something very remarkable about the methods of Pasteur. He was a great

master of methods and of method. The particular method that dominated him was that of the chemist. His work consisted in the separation, the purification, the recognition, and the characterization of individual things. These happened to be organisms instead of crystals. It was because he had exceptional ability to purify, to isolate; because he had an intuition of what is pure and what is a good experiment—the chemist's intuition—that he accomplished his results.

Pasteur met with much opposition and did a great deal to stimulate it. He fought. He fought vigorously, and he seems to have used polemic as a means of conviction. No doubt he enjoyed fighting. There is an amusing story of an episode in the Académie des Sciences. Some of his most certain results had been attacked by colleagues, who were quite unjustified in their criticisms. He crushed them with his answer, then turned to one of them and said, "Do you know what is the matter with you? You are incapable of observing!" Then to the other, "And you, you are incapable of reasoning!" There was a murmur of protest from the Academy, and Pasteur said, "My vivacity has carried me away. I present my apologies to my colleagues." Then he hesitated—"May I, now that I have admitted my fault and made amends, make a statement in extenuation? What I said was true, absolutely true!"

II.

There is a larger view of Pasteur's influence. He studied, among other problems, that of spontaneous generation, and proved that there is no such thing in any experiment that has ever been made. Perhaps, if there be such a phenomenon, there is no great hope of our ever observing it. This question has attracted men in all ages. Aristotle has discussed it; it interested Harvey; it was studied by Redi in the Seventeenth Century; it was studied by Spallanzani in the Eighteenth Century; and by Schwann, one of the ablest advocates of the cell theory, in the early Nineteenth Century. Several of these investigators had the solution almost in hand; but they lacked the experimental skill of Pasteur, they lacked his critical faculty and his power to complete what he had begun. This study of spontaneous generation was important because it removed one of the greatest sources of uncertainty in the interpretation of natural phenomena.

Yet there is something very much larger about Pasteur's work than even this.

It is customary to recognize as a department of biology the science called ecology. The name is abominable; the science is one of great beauty. Ecology concerns the relations between living things and between living things and their environment. It is, in fact, nothing but the better part of natural history. Let us ask ourselves what is going on on the surface of the earth. We know that water is circulating in the meteorological cycle. A part of this, and dependent upon it, is the organic cycle. The essential features of the organic cycle were plainly perceived by Lavoisier, who described it well in chemical terms, and who saw clearly that fermentation and putrefaction are essential stages of the cycle. But before Pasteur's day no man could have a clear idea of many of the interrelations between organisms. Pasteur, by separating microörganisms and accurately characterizing them, made it possible for men in imagination to put these pure cultures back into nature where they belong and to understand their manifold rôles. Thus he withdrew a veil from before our eyes.

That, very imperfectly stated, is the great achievement of Pasteur from the standpoint of pure science. He revealed a great new realm of nature that had not been understood before and that we are capable of understanding clearly today.

It was not good luck that led him to such success. Somewhere he has himself said, "In the field of observation chance favors only the trained minds." And that is peculiarly true of him. Pasteur made good experiments in the same way that Rembrandt made good pictures, or Beethoven good symphonies—he could not help doing so. His mind was trained; his hand was trained; and, what is not less important, self-trained.

There is one further characteristic of Pasteur's work that I wish to mention before turning to more general considerations, and that is his interest in what is concretely useful. To be sure, he was called upon by his country to solve the problem of the diseases of the silk worm; but long before this he had perceived that in industry, as in medicine, peculiarly interesting and important theoretical problems are involved. Why is this true? It is because in the old industries,

by a long process of adaptation, in spite of the fact that men have often not understood what they were doing, discoveries have been made and preserved. It is a case of the survival of the fit process. Any man who, with theoretical understanding, has ever been called upon to study a practical question must have been struck by the fact that the old useful arts are full of interesting scientific problems. Pasteur discovered this in Lille, and he never forgot it. The truth of the conclusion is confirmed by his whole career.

III.

Men of science are likely to be philosophical. Few are so free from philosophical preoccupation as was Pasteur. It will be interesting, I think, to reflect a moment upon this subject.

There are several kinds of philosophical interest that may arise from science, and we can find them all illustrated by men who were Pasteur's older or younger contemporaries in France. There is, for example, the imaginative creation of the mathematical physicist, one of the most extraordinary productions of the human mind. This is well illustrated by the work of Henri Poincaré. It is perhaps not too much to say that Pasteur was incapable of such work. Certain it is that abstract principles did not seriously occupy his mind.

Again, if mathematical physics presents certain kinds of problems, biology presents others of a different nature. One might suppose that Pasteur would have been attracted toward the general questions of biology, such as the problem of organization. Few among the great biologists have failed to reflect upon the mysterious integration of all the processes that go on in the living organism, how this comes to be, how it is to be conceived and described. Claude Bernard is one of the greatest names in the history of this question. Pasteur passed it by almost entirely.

Another type of scientific philosopher is the encyclopedist, splendidly represented in Pasteur's day in France by the chemist Berthelot, and by the mathematician Joseph Bertrand. So far as I know, there is nothing of the encyclopedist about Pasteur. He was far too busy making experiments to be concerned with collecting and carrying in his head vast stores of knowledge. That was not for him. It is even

said that he paid scant attention to the current literature of his own special subject.

Last, there is the tolerant, critical humanist, the man of large experience in the affairs of the intellect. Such a man was Renan, but not Pasteur. Pasteur was a fighter, a man who believed perfectly and without qualification in what he knew to be so. Beyond this he clung to certain ideas which he had acquired in his childhood and which he loved.

In order to perceive the really extraordinary contrast between Pasteur and a man who has arrived at a balanced philosophical outlook upon life, it will suffice to read a few of the remarks that Renan made in answer to Pasteur when Pasteur was received into the Académie Française. The occasion was an interesting one. Pasteur had succeeded Littré, the high priest of the positivism of his day in France, and was called upon to praise a man whose views he could not share. Renan replied in part as follows:

> See, Sir, what strange people we are, and what irony seems attached to our efforts. Even in the matter of truth our qualities are less useful to us than our defects. One must not be too perfect. If M. Littré had been less sincere he might have avoided some mistakes. . . .
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> You prefer another philosophy to that of Littré, one which you suppose will find a "last refuge" here. Ah! do not count too much upon that, Sir. The zone of our literary patronage is very wide. It extends from Bossuet to Voltaire. We often like to give sanctuary to the defeated; the cause which should find a last refuge here might well be in very bad case. We do not protect doctrines, we discern talent. That is how we never have to make retractions or denials. Everything passes away but we do not pass away, for we are dependent upon only two things, which we trust will last for ever in France: intellect and genius. We respect every form which clothes a noble belief. You, for example, use two terms which I should never employ: idealism and materialism. The end of the world is the idea; but I know of no case in which an idea can be produced without material; I do not know any pure spirit, nor any work of pure spirit. The divine work is accomplished by the inborn tendency towards the good and the true which exists in the universe; I do not know whether I am a materialist or an idealist.
>
> It is prudent not to associate the end of moral beliefs with any system. The answer to the riddle which troubles and fascinates us will never be given us. As for myself, when anyone denies these fundamental dogmas, I feel inclined to believe them; when they are stated otherwise than in beautiful poetry, I am seized with unquenchable doubts. I am afraid of making too sure of them, and like the mystic described by Joinville, I am sometimes inclined to destroy heaven for love of God. It is doubt for which one deserves credit. . . .

There are in the intellectual order, apparent contradictions which do not exclude similarity. There are minds which are as impossible to bring together, as—to make use of a favourite comparison of your own—to put two gloves one into the other. And nevertheless both gloves are equally necessary; each is the complement of the other. Our two hands cannot be superimposed one upon the other, but they can be joined. In the great womb of nature the most diverse forces join and combine to bring forth a result of majestic unity. . . .

Your absolute devotion to science gives you, Sir, the right to succeed such a man and to recall his great and hallowed memory to our minds. You will find in our meetings relaxation for a brain continually occupied with fresh discoveries. . . . You will observe with some interest the efforts of our critical philosophy to make allowance for error, by distrusting its proceedings and limiting the scope of its own statements. Seeing how much may be taught even by apparently frivolous literature, you will get to believe that the discreetly expressed doubt, the smile, the delicate wit of which Pascal speaks, may have their value. You will not have experiments to make here, but that simple observation of which you speak so ill, will suffice to procure you some very pleasant hours. We shall communicate some of our diffidence to you, and you will give us of your assurance. You will, above all, bring us your glory, your genius, and the fame of your discoveries.

On another occasion, at the reception of Joseph Bertrand as successor to the chemist Dumas into the Académie Française, Pasteur was called upon to respond, and for once permitted himself to express some of his own philosophical ideas. No man, indeed, however unphilosophical, can avoid acquiring some philosophical ideas of his own. Pasteur, like everyone else, but far more intensely than most other men, had a philosophy of life. But it was a simple and concrete philosophy which he expressed as follows:

True merit in a true democracy; that is what you both [Dumas and Bertrand] represent.

True democracy is that condition which permits every individual to put forth his maximum effort in the world. . . . Why must it be that beside this fruitful democracy there is another, sterile and dangerous, which under the pretext of fancied equality, dreams of absorbing the individual in the state and destroying him? This false democracy . . . is the cult of mediocrity. It is suspicious of everything that is superior. . . . It may be defined as the league of all those who would live without working, consume without producing, reach positions for which they are not prepared and honors of which they are not worthy.

Pasteur is truly regarded by all Frenchmen as the embodiment of the qualities of their race. He was intensely patriotic, with a nationalism which does not yield to that of any man. He felt no greater

desire than to serve his country and to repair her misfortunes, no greater happiness than when he realized that he had done so.

The greatness of Pasteur as a man rests upon the simple virtues that it is disaster to forget; filial piety, patriotism, love of work, love of truth, a deep sense of personal responsibility. But who shall explain his greatness as a discoverer? He, like Faraday, is the very illustration of scientific method, which is of the domain of mind, not of mere logic. If we are ever to understand scientific method, it must be through an understanding of men like Pasteur.

We discern in him a perfect balance between action and reflection, between self-confidence and self-criticism. Intensely concentrated without interruption during a half century upon his concrete problems, sanguine and cautious, rapid and deliberate, intuitive and rational, imaginative and—unimaginative, an idealist and a naïve realist, he marched from victory to victory.

LAWRENCE T. HENDERSON.

REMARKS ON DR. HENDERSON'S ADDRESS ON PASTEUR.

By DR. ETIENNE BURNET,

Pasteur Laboratory, Tunis.

I shall not venture to add anything to the remarkable address delivered by Professor Henderson.

Pasteur was a chemist; a chemist is particularly entitled to praise the life and services of Pasteur.

There is only one man in the world who would be able to add anything to what is known about Pasteur. This is Dr. Roux, who was more than 20 years the assistant, then a co-worker, with Pasteur.

I had many times the privilege to hear Dr. Roux speak about Pasteur and point to the essentials of Pasteur's genius and life.

There is generally in such great men one favorite, one leading, thought, that enlightens them very soon in their youth and remains for life their most intimate faith and joy, like their "Star in the East." Thus Elie Metchnikoff, we know, was forever a lover of myxomycetes. Pasteur was always in love with crystals. He ever believed that molecular dissymmetry would explain the origin of life, and was often repeating: "What would be a man, who should have left instead of right albumines?" "What a pity," he said again, "that I have given up the study of crystallography!" Such an utterance helps us to excuse more indulgently that lady who, on account of a taste for drawing that was really displayed by Pasteur in his youth, said to him, at the climax of his career: "Ah! Monsieur Pasteur, what a pity you have missed your calling!"

Despite his partial love of crystallography, Pasteur at once realized that the study of ferments should overthrow the traditions of medicine. According to some critics, the logical, straight development, which we wonder at in Pasteur's work, is an artificial scheme that was, so to speak, adopted afterwards, for beauty's sake, because nature

never acts so regularly, and genius is an impulse of nature. Such an opinion is quite false. Pasteur was from the first step and at every step conscious of his aim. His star, indeed, was a Morning Star. And sooner than is commonly believed, because of his always meditating upon the achievements of Jenner, he foresaw the value of microbian vaccination. The only man in the world in his time, he bore in himself, like an obsession, this leading thought: "We must immunize against the infectious diseases." As soon as Dr. Roux had discovered the diphtheric toxin, Pasteur immediately said to him: "Now you must try some vaccination with it."

Pasteur, who appears as a precise, deliberate, matter of fact experimentator, was endowed with an imaginative power, a thrilling wonder to his disciples. "He would," Dr. Roux says, "expound the most profound and unexpected ideas, and propose the boldest experiments. Nothing was *a priori* absurd to him." In the laboratory conversations he was somewhat slow to start, but soon excited and stirred, he gave way to fireworks of vast thoughts and audacious schemes. It is quite true that, on the day of his wedding, he overlooked the time. And later, very often, after a dinner attended by guests, Pasteur would wait a little, and then turning aside to his assistant say: "Let us go and examine our cultures." He knew how to spare his assistant's time as well as his own. For instance, he usually answered letters very punctually. Once Dr. Roux, entering the laboratory in the morning, met Pasteur, who had already opened and answered some letters. Nay, he had even, by error, opened a letter addressed to Dr. Roux. So he handed the letter to him with a word of apology and added: "Never mind, . . . let's go to work. . . . I wrote the answer for you, too."

He was certainly a good, tender-hearted man, but he never lost sight of his thought and work. When he received, by telegraph, the news of the death of his assistant, Dr. Thuillier, who was studying cholera in Ægypt, he felt the blow like a father, and remained silent for a time; then, suddenly: "Provided they did not forget to examine his blood."

Pasteur's scientific life begins in 1866, the day when, as a young graduate of 22, he read a paper by Mitscherlich, on the tartrates and

paratartrates; it ended with comments on vaccination against infectious diseases and hydrophobia. From end to end he is the same super-man.

His family, his disciples, his country, will appreciate with a particularly deep feeling of gratitude the tribute paid to him by those who had elected him as a companion to the American Philosophical Society.

PERMEABILITY AND THE INCREASE OF VOLUME OF CONTENTS OF LIVING AND OF ARTIFICIAL CELLS.

BY DR. D. T. MACDOUGAL.

(*Read April 21, 1923.*)

GENERAL.

Our present knowledge of permeability—of the way in which water and dissolved materials pass into and out of living cells—rests chiefly upon experiments upon the eggs of fishes, starfish and other marine organisms, on vegetative cells of algæ, and upon the tissues of a few higher plants. The animal eggs used are of a type in which the passage of material into and out of the cell is controlled by a thin external membrane. This membrane is variously taken to be a protein, a lecitho-protein, or a protein-lipin-soap combination by various observers.

When the membrane is intact in an egg the interchange between the cell and the medium is at a very low rate. Disturbance of the membrane by a sperm or by a wide range of physical stimuli is followed by the increase in permeability which accompanies, or constitutes, an essential feature of fertilization. The series of theories which have been offered as to these effects box the biological compass and most of us are intrigued with the last interpretation presented, especially if it be novel or unexpected.

The actual or functional importance of permeability is perhaps greatest in the plant in the root-hair action. These structures being the tubular extension of epidermal cells on the young and actively growing part of the root, although they sometimes persist and are active for 70 or 80 days. All exchanges between the soil and the medium must take place through these cells. The root-hair is at first a dense mass of protoplasm limited by a fairly definite membrane, but its development quickly carries it to a stage in which the interior is occupied by an enormous vacuole, while the protoplasm forms a

thin layer lying against the wall. Permeability here becomes a question of the passage of material through both wall and protoplasm, under conditions which will be described below.

Determinations of permeability have been made by a wide variety of methods, including the study of visible and microchemical changes in the cell, analysis of sap and of the medium, measurement of hydrogen-ion concentration in the sap and in the external solution, measurements of the electrical conductivity of the cell and of the medium, estimations of metabolism, plasmolysis, plasmometry, measurements of tissue tensions, and of diffusion, and finally by measurements of changes in weight and volume of living cell-masses induced by the entrance or loss of water and of other substances.

This last-named method seems to have been used chiefly, if not entirely, with blood-corpuscles in animals, and with root-tips in plants. In the earlier work by Lunegardh in 1911 the time in which a root would undergo certain increases in length was taken as the index of the rate of entrance of salts. The later work by Stalfedt, and by Kahho in 1921 is of especial interest. The last-named made micrometic measurements of the initial contraction resulting from the immersion of root-tips in salt solutions, and also of the subsequent expansion. The ratio of the expansion to the contraction was taken as the measure of the action of the salt solutions.[1]

The Purposes and Methods of the Present Study.

The present study of the subject was made for the purpose of obtaining facts and establishing principles which might be of use in the interpretation of major and minor variations in the rate and course of growth during the extensive observations which have been carried on in the last few years. Measurements of growth are most effectively made in terms of weight and volume. Determinations of the swelling of biocolloids concerned in growth expansions have been made by such methods as have been also described in full in previous papers. It was therefore found highly expedient to obtain the effects

[1] Lunegardh, *K. Svenska Vet. Akad. Handl.*, 47, No. 3, 1911. Kahho, H., "Ein Beitrag zur Permeabilitat des Pflanzen-protoplasmas fur Neutralsalze," *Biochem. Ztschrift.*, 123, 284, 1921.

of the common bases and their salts on permeability in comparable terms. The effects of various solutions on living cell-masses have been recorded by the auxograph.[2] The flat joints of Opuntia which is abundant about the Desert Laboratory, and grows profusely at the Coastal Laboratory, furnish a plate of material larger than the palm of the hand from which sections of material which will have two epidermal surfaces intact and fairly homogeneous masses of thin-walled cells. The sections range from 3.5 mm. to 6 mm. in thickness in different specimens, and are cut with epidermal surfaces of about 1 sq. cm., excluding the larger fibro-vascular tracts. The smaller ones ramifying minutely and thoroughly among the parenchyma cells, with the large intercellular spaces facilitate the ready penetration of solutions into all parts of the mass, so that every cell is quickly subjected to the action of any solution in which the section may be immersed. Trios of such section are placed in a stender dish, and the swinging vertical arm of the auxograph is brought into bearing on the center of a triangular glass plate which rests on the sections. The record which is made is an integration or average of the action of three sections.

The composition of the living material has been made the subject of extensive inquiries in this laboratory, and the information thus made available has had no little value in the present connection.[3]

Estimation of the concentration and ionization of immersion liquids and of the cell-sap of sections have been made by the conductivity method.

The use of the artificial cell made it possible to determine the osmotic action of the contents, the amount of exosmose of the organic contents, and by conductivity tests the amount of the electrolytes lost from the immersion liquids to be absorbed or combined with the material of the external layers or diffused into the cell-contents. Discussion of some of these features is reserved for a future paper.

The structure and composition of the protoplasmic layer and of the walls of such cells and of root-hairs is a matter of prime interest.

[2] MacDougal, D. T., "Hydration and Growth," Publication No. 297, 1920, pp. 11–13.

[3] Spoehr, H. A., "Carbohydrate Economy of the Cacti," Publ. Carnegie Inst. of Washington, No. 297, 1919.

The generalized conception which may be formed as a result of recent studies by various workers is that the plasmatic layer is a mixture of the colloidal material occurring in the cell. These include the albumens, pentosans, lipins, soaps, and their compounds in a many-phase emulsoid system. The final structure is, of course, beyond the technique of the cytoloigst; the use of the ultra-microscope may yield something in its elucidation. Whether the X-ray photograph may be employed toward the elucidation is doubtful, at least in the present stage of our researches, in which we must proceed principally upon theories of colloidal arrangement and action.

The lipins, which are now conceived to be an important part of the mechanism of respiration in the plant, if not actually the scene of the pivotal processes, are abundantly present in active cells. Their participation in a mosaic membrane by the theory of Overton of 30 years ago now yields to a consideration of their localized occurrence and condition as determined by direct observations. According to the conclusions of Hansteen-Cranner, these substances are in the form of an irregular deposit in the external part of the protoplasm, sending strands or processes into both the wall and into the plasmatic mass. The lipins being, some of them, both fat- and water-soluble, afford some interesting possibilities in the way of allowing the passage of both salts and fats into and out of the cells. So far we have the picture of a denser phase of this material carried in a continuous phase of water-soluble lipins or phosphatides in which condition only water-soluble substances might diffuse. A reversal of phase by which the denser portion becomes continuous would be necessary to permit the passage of oil-soluble material.

The wall, outside of its lipoidal component in the stage in which it is a control of permeability, has a skeletal structure of cellulose, swelling slightly in water, but entirely insoluble. A mixture of lipins mannosans, glucosans, and pectins, all liquifying or going into solution in water, occupy the spaces of mesh work. Pectates tend to accumulate in the middle portion of the wall between joined cells stratifying as a middle lamella. In the case of a root-hair this material forms the external part of the wall.

The absorption of water and of dissolved substances, or the pas-

sage of material out of the cell, are processes determined by the colloidal condition or state of combination of the above materials. It is obvious that the physical problems presented are far more complex than those of an osmometer with a durable membrane of clay parchment, collodion, or rubber.

The peripheral layer of a plant cell is permeable to water in all of the stages of interest in the present connection. The walls of epidermal and other cells may and do become waterproofed, but such cells are relatively inactive or wholly at rest.

On the other hand, the wall may not only permit the passage of water, but also all of the common salts. In such cases the control of material passing into and out of the cell lies chiefly in the plasmatic layer. It is only in cells in which this condition exists that the plasmolytic method of determining the osmotic value of the cell-sap may be employed profitably. In the root-hair, which is the principal absorbing organ of the plant, the condition of the wall and of the plasmatic layer together determine the permeability of the cell as a whole.

It is to be noted that by permeability the penetrability of a layer to ions is generally denoted, although some authors use the term to include the passage of water. The diffusion of ions is also generally taken to be independent of the passage of water through a dense membrane. The penetration of the external layers of the cell by ions and their adsorption and combination with its components may alter the character of the membrane in such manner as to affect osmosis, though it does not seem to be clearly recognized by many authors. This action results in interferences with the diffusion of other ions and also affects the manner and rate of osmotic action. The observations carried out with the artificial cell and with the sections of *Opuntia* make this clear. Both the living cell-masses and the artificial cell have been operated under conditions in which the immersion liquid was hypotonic to the cell-contents mainly; slightly hypertonic in some cases.

The Artificial Cell and Its Action.

The artificial cell used was an improvement of the design described before this society in 1922. As modified the cell was con-

structed of material more nearly approximating that of the plant with possibilities of greater biological interest, and its action was estimated by changes in the volume of the contents measured as outflow.[4]

In the construction of such a cell, an extraction thimble of filter paper double thickness (Whatman, or Schleicher and Schöll), 33 x 80 mm., is dipped in a mixture of equal parts pectin and agar liquified at a temperature of 60° to 80° C. This is now dropped in 90 per cent. alcohol for 5 minutes, which dehydrates the colloids, leaving them in a precipitated or aggregated condition in the meshes of the cellulose of the wall. After the alcohol has evaporated, the shell is now filled with a 3 per cent. solution of lecithin or other preparation of lipoidal and albuminous material in water. The lipin is carried into the spaces between the particles of agar and pectin and is locked there by the swelling of these particles in the water. After draining a few minutes, a section of glass tubing 2 cm. in length is fitted snugly in the mouth of the thimble to give it firmness, and a rubber band is snapped around the whole to hold the glass reinforcement in place. About 10 cc. of agar or agar mixture is poured into the shell, which is turned in the hand to allow this to spread and set over the inner surface of the wall, where it should form a layer about 1 to 2 mm. in thickness. The stopper is inserted and the cell may be filled with suitable solutions to test its absorbing action in various media or immersion liquids. An initial absorption of water by the colloidal material in the wall takes up some of the water of the solution in the cell. As soon as these colloids are satisfied, a small amount to replace the loss, never amounting to more than a few cc., is dropped in the filling tube. Any further increase in the contents will result in the displacement of some of the contents, which will exude from the outlet, drop by drop, and should for convenience be collected in a small graduated cylinder where the amount may be read at a glance.

The cell as described holds about 50 cc. of "cell-sap," and the most reliable results are secured by supporting it upright in a beaker of immersion liquid holding about 250 cc., with the top of the stopper at the level of this liquid and with the outlet tube resting on the rim of the beaker.

[4] MacDougal, D. T., "The Probable Rôle of Lipoids in Growth," *Proc. Amer. Phil. Soc.*, 41, 33, 1922.

The absorbing cell of the plant has a sap in which as much as half of the osmotic action is to be attributed to the salts present, the remaining fraction being attributable to sugars, amino-acids, and other organic compounds. These substances have in such instances interlocked with the mechanism of the cell, and when the effects of reagents on the permeability of these cells is tested, it is to be understood, of course, that the results imply additions and displacements.

The present use of the artificial cell being that of determining the action of salts on a colloidal-osmotic mechanism, the cells are first set up with the "vacuolar" contents of sugar, into which, of course, are dissolved as the cells are set in action, some solution of the albuminous compounds, pentosans, and lipins of the external layers. The principal experiments were carried out with sugar contents of 10 and 20 per cent. solutions with osmotic values of nearly 8 and 16 atmospheres, which are common among the plants about the Desert Laboratory.

After the initial action of any series of cells was determined and various single salts had penetrated the cells the immersion liquids from which absorption was taking place were replaced with resulting conditions somewhat similar to those of the living cell.

The widely divergent suites of data that may be secured by the hydration of material from different plants suggest varying composition of the cell. It was therefore arranged that artificial cells should be constructed which should show the action of different colloids in the external layers. Relative permeability is taken to be denoted by the outflow from cells immersed in various solutions. Such data are also supported by determinations of the resistance or conductivity of the immersion liquids or of the cell-contents to ascertain the behavior of the electrolytes, which may have passed into the cell, absorbed by the colloids or combined with some of the material of the external layer. Estimations were also made of the exosmosis of the organic material from the cell-contents.

The albuminous components were omitted from the cells of the series below. The cellulose walls were infiltrated with a mixture of equal parts of agar and pectin, and then with lecithin. Later a plasmatic layer of agar was added. The action of this series is given in Table 1.

TABLE 1.

Endosmose of Agar-lecithin-pectin Cells Filled with a 10 p. ct. Sugar Solution (Nearly 8 Atmospheres) at 16–22° C.

Immersion liquids at 0.01M.	KCL.	NaCl.	$CaCl_2$.	($NaCl$ / $CaCl_2$) 0.0002M.	Water.
Osmotic value in mm. of mercury	28	27	40	28	—
Hydration value on agar	1305	1145	705	—	1610
Initial absorption from cell-contents	4 cc.	0.9 cc.	0.0	0.7 cc.	0.8 cc.
Total of two cells in 24 hours	1 cc.	2 cc.	6.5 cc.	2.7 cc.	7 cc.
Immersion liquids changed to	$CaCl_2$	$CaCl_2$	KCL	No change	No change
Total of two cells for 20 hours	4 cc.	9 cc.	3.4 cc.	3.6 cc.	4.5 cc.
Immersion liquids changed to	NaCl	KCl	$CaCl_2$	No change	No change
Total of two cells for 24 hours	0.3 cc.	0.7 cc.	6.3 cc.	3.6 cc.	3.4 cc.
Immersion liquids changed to	$CaCl_2$	$CaCl_2$	NaCl	—	—
Total of two cells for 12 hours	1.6 cc.	1.6 cc.	1.2 cc.	—	—

The following general features are observable in the action of the cells in Table 1:

1. The relative effects of the various solutions on the action of the cells are approximately parallel to their effect on the hydration of agar, and in conformity with the electromotive series K, Na, (Na + Ca), and Ca.

2. The data given show total action under the separate conditions, with some estimation of rate. The rate of intake is highest in pure water in the beginning. Like the living cell, the period of expansion is shorter than in cells subjected to the action of the salts. The initial rate in calcium is higher than in solutions of sodium or potassium, paralleling the results of Stiles as to absorption of these kations. The initial rate of sodium is higher than that of potassium. The initial rate in calcium when used to replace sodium is higher than that when potassium is replaced, in the earlier life of the cell. Replacement of calcium by potassium lowers the rate, which rises with the reverse replacement.

3. Sodium-calcium solutions have an initial effect not markedly different from that of the sodium alone, but give rise to a steady continuing effect.

4. The amounts of endosmose shown by the various cells are due to the osmotic action of the sugar solutions in drawing water into the cells, through membranes which are variously affected as to per-

meability to water, to sugar and the entering ions. The endosmotic effect alone is seen in the cells immersed in water. Exosmose was the subject of special tests.

A series of cells was now prepared in which the inner material of the wall was composed of an emulsion of gelatine 10 per cent. solution in water, to which was added an equal amount of 3 per cent. lecithin solution; and 5 cc. of a solution of 1 part per thousand of potassium oleate had been stirred in the gelatine. The resultant mixture was clear and homogeneous. The action of such cells is shown in Table 2.

TABLE 2.

ENDOSMOSE OF CELLS WITH AGAR-PECTIN WALLS, TREATED WITH GELATINE-POTASSIUM-OLEATE-LECITHIN AND FILLED WITH A 20 PER CENT. SUGAR SOLUTION.

Immersion liquids at 0.01M.	KCl.	NaCl.	$CaCl_2$ (0.007M).	Seawater.	NaCl 0.01M, $CaCl_2$ 0.0002M.
Total of two cells for 60 hours	15.4 cc.	25 cc.	14.7 cc.	15.3 cc.	18.5 cc.
Immersion liquids changed to	NaCl	$CaCl_2$ 0.007M.	NaCl	NaCl	NaCl
Total for one cell for 24 hours	5.2	4.0	0.7	2.9	2.4

The principal features of the action of this set of cells are as follows:

1. The highest initial rate of absorption of water is shown by the cells in a sodium solution, which is in excess of that in water. The rates in potassium, calcium, and in a sodium calcium solution are not markedly different. Replacement of potassium by sodium resulted in an acceleration. Retardation ensued when sodium was replaced by calcium, or calcium was replaced by sodium. Practically no retardation ensued when sea-water was replaced by sodium, but retardation was marked when a sodium-calcium solution was replaced by sodium.

2. It is to be noted that the calcium was used at a reduced concentration to lessen the osmotic inequality with other cells, and that the cells were "short-lived," showing no regular action after the

period given. The cells in Table 1 were active 112 hours; those in Table 2, 84 hours.

3. The inclusion of an emulsion of gelatin in the cell is followed by important features of action of the artificial cell, including a high rate in sodium solution.

A series of cells was set up in which the gelatine and lecithin were mixed together, giving a milky emulsion which may be taken as an indication of large suspensions of the lecithin in the gelatine. These cells were set up and allowed to run to a point where the determination of the composition of the liquids inside and outside the cells could be tested. The results are as follows:

TABLE 3.

ENDOSMOSE OF AGAR-PECTIN-GELATINE-LECITHIN CELLS FILLED WITH 20 PER CENT. SUGAR SOLUTION AT 12–18° C.

Immersion liquids	KCl 0.01M.	NaCl 0.01M.	$CaCl_2$ 0.07M.	Seawater 0.01M. for Na.	Water
Total for 2 cells for 70 hours	22.2	25.7	27.6	22.6	24.1

1. The highest initial and continuing rate of absorption or endosmose was in the calcium, which was in excess of that in water. The rate in sodium was higher than that in sea-water, water, or in the potassium solution. The differences shown above are small, but the action of the pairs of cells were steady and uniform that the differences may be taken as significant of the action of external layers made up as above.

2. The rate during the last 24 hours was one third that in the first day in K, Na, Ca, something less in sea-water, while in water the rate during the last 24 hours was about one half that in the first day. The rate in water is one due solely to the lessened concentration of the sugar solution due to excretion through the outlet tube and to exosmose.

3. The immersion liquids were tested for sugar at the end of 70 hours. The potassium solution had become a 2.04 per cent. sugar solution, the sodium solution contained 2.07 per cent. sugar, and the calcium solution had become a 2.04 per cent. sugar solution, the sea-

water had become a 1.81 per cent. sugar solution, and the water as an immersion liquid had become a 2.6 per cent. sugar solution. These data taken as indices of exosmosis are without special significance except in the case of sea-water. In this as a balanced solution the external layers of the cell were less permeable to sugar than in the single salt solutions. The greatest permeability was shown by cells immersed in pure water.

4. The resistance of the immersion liquids and of the cell-contents showed the following changes during the 70-hour period:

TABLE 4.

Immersion Liquids.	Original.	Final.	Increase.	Percentage of Increase.
KCl	307	329	22	7.2
NaCl	362	382	20	5.5
$CaCl_2$	258	290	32	12.4
Seawater	290	322	22	7.6

The interpretation of the above data shows that the withdrawal of kations from the immersion liquids was relatively greatest in the calcium, and least in the sodium with the potassium showing a higher rate than the sodium. Withdrawal, absorption, or penetration of the kations from sea-water was slightly greater than from a sodium solution. The kations concerned would be arranged in the order K (sea-water), Na and Ca in the expansion series, and Na, K (sea-water), Ca in the order of the increased resistance of the liquid indicative of withdrawal and penetration or absorption by the cell.

If we now pass to the cell-contents, it is to be pointed out at the beginning these were simply 20 per cent. sugar solutions in pure water with a resistance of something over 14,700 ohms. After the cells had been in action 70 hours the kations from the immersion liquids had not only made combinations and unions with the materials in the walls, but had passed into the cell-contents, lessening the resistance enormously as shown below.

The resistance of the cell-contents had been lessened about the same amount in sodium, calcium, and sea-water by the passage of the ions through the external layers into the vacuolar cavities. The

TABLE 5.

Cells in	Resistances.	Excess over Original.	Excess over Final of Immersion Liquid.
KCl	360	48	26
NaCl	425	44	64
CaCl	315	30	62
Seawater	364	42	64

amount of potassium which had passed through, however, was so great that the resistance of the cell-contents had been lowered to a point not widely separated from that of the immersion liquid. If the relative amounts of penetration be indicated by the proportion of the difference between the original resistance of the immersion liquid and the final of the cell-contents, a series would be formed of the bases which have penetrated into the cell, which would begin with potassium as the one occurring in the largest proportion and form a decreasing series K, Ca, Na, sea-water. The above relations are to be understood as pertaining to this particular cell construction and composition.

Changes in Volume of Living Cell-masses Due to Alterations in Permeability.

The cell-sap or vacuolar contents contain, in addition to the sugars, amino-acids and salts of the common bases, including nitrates, sulphates, and chlorides. Half of the turgidity of the cell may be ascribed to the osmotic action of such salts. When cells with such contents are placed in distilled water the deficit, which is all but invariably to be recognized, is taken up by the entrance of water with a consequent increase in volume. In actual practice the cell remains in the fully distended condition a length of time dependent on the temperature, when the external layers of the cell becoming more permeable to water allow it to escape with consequent contraction. Such increase in permeability may be taken to be due mainly to the solution out of material from the wall and to the increased hydration of the colloids.

If now solutions of salts be added to the water in a similar experiment, the permeability of the wall will be affected by the action

of these salts in forming compounds with the material in the layers of cell-material, the solution out of some of the material, the colloidal action of the kations and anions on the colloidal aggregates of the wall and plasma. The result may be an increase or a contraction of the cell according to conditions. The osmotic action of the external solution will be a factor in whatever does take place. The diffusion of the ions into the cell will be proportional to their ionic velocities, which in the common bases will be as K 64.7, Na 43.6, Ca 51.8. Their action in aggregating effects will be in proportion to the unit charges they carry which will be in the above order, but with the least effect by potassium and the greatest by calcium.

The aggregation effects of these bases is in general within a range in which the permeability of the colloidal material of the cell to the acting ion or to other ions may be nearly reduced to zero, yet the passage of water is still possible, conforming to the popular conception of a "semi-permeable" membrane.

Now, when cell-masses which have been fully hydrated in water after the manner in which this was done by Kahho with root-tips is placed in a salt solution which is isotonic or slightly hypertonic to the cell-sap, it is found that a contraction ensues which continues for a short time, after which expansion takes place, which does not, however, carry the cell to the volume which it had when fully hydrated in distilled water. The proportion of the contraction which is regained is taken by Kahho to indicate the degree of change which has been produced in the permeability of the cell. Thus NaCl at 0.0141M gave a resumption of 29–30 per cent., at 0.181M gave 35–54 per cent., while roots in $CaCl_2$ at 0.134M showed no return toward the original dimensions. These solutions being isotonic, Kahho concludes that the penetrability of the potassium is greatest, but that the permeability is lessened most by the calcium with the action of the potassium lying between.

The above tests were carried out with care and exactness by Kahho, but it was important that they should be repeated with other material. Joints of *Opuntia* were chosen for this purpose. Living sections of this material (the structure of which is described on page 2), which were in a condition in which they would swell 150 to 160

per cent. in thickness in pure water, were placed under the auxograph in water, and after 6 to 9 hours, when the increases amounted to 120 to 130 per cent., the water in the immersion dishes were replaced with graduated series of potassium, sodium, and calcium chlorides.

This method of auxographic measurement not only enables the observer to see the exact thickness of the sections at any moment, but he has also a visible record of the changes from the beginning, and with the ten instruments available it was possible to carry a large number of tests through simultaneously at the identical temperatures, which thus did not need to be kept constant or under uniform illumination. The immersion liquids in the tests below varied from 16 to 20° C.

The plan implied that a series of sections were first hydrated in water to the extent indicated, then the water was replaced by salt solutions beginning with those in 0.01M concentration. At this concentration no disturbance of the course of slow enlargement was noticeable in the records. At concentrations of 0.03 to 0.04M, however, a slight retardation lasting for an hour or more was noticeable. At concentrations of 0.05M for KCl, NaCl, and $CaCl_2$ a slight but positive contraction ensued. This did not take place in sea-water until a concentration of 0.06M for the contained Na was reached. After contraction for an hour or two expansion was resumed as shown in Fig. 1. The consequent increase could not be determined with sufficient exactness to be of value.

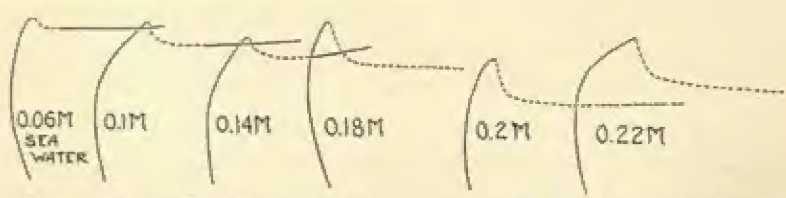

FIG. 1. Facsimile of auxographic records of living sections of *Opuntia* which were first hydrated in water at 16°–19° C. for 6 to 9 hours, then placed in solutions of sea-water. When the concentration reaches 0.06M a slight contraction followed by expansion takes place. At concentrations above 0.16M plasmolysis ensues and the contraction is permanent.

It is to be noted that Kahho found that roots subjected to the action of NaCl at concentrations from 0.0150 to 0.214M to KCl at

0.161 to 0.210M showed an initial contraction followed by an expansion. $CaCl_2$ at 0.134M produced a contraction which was not followed by an expansion. It is probable that this would have occurred in a lower concentration. The above, however, are taken to be slightly hypertonic to the cells of the root, hence the contraction.

The solutions given above which produce a contraction of the sections may be taken in like manner to be hypertonic to the cells. That they are not isosmotic is obvious. That the contraction of the cells due to increased permeability and loss of water with perhaps some of the dissolved contacts is brought about by the colloidal action of the various salts seems plain.

The aggregating or combining effect of the salts becomes even more obvious when the effects of the higher concentrations are considered. Sections in concentrations above $CaCl_2$, 0.07 lost the power of expansion, while this did not occur with Na until a concentration of 0.14M was reached, sea-water at 0.16M, and with K until a concentration of 0.18. It may be safely assumed that these concentrations serve to rend the plasmatic layer from the wall in an irreversible plasmolysis.

This effect is evidently not one of tonicity, as the isosmotic values of critical solutions which produce an irreversible contraction are widely apart. The concentrations, however, do form a series expressing the relative penetrability or permeability of the kations concerned. The aggregating effect which would produce a permanent lessening of permeability is designated by the concentrations given and the three bases form the series Ca, Na, and K.

As a variation of the above test sections which were fully hydrated in water, having been immersed for 24 hours and upon the threshhold of shrinkage, were subjected to the action of the above solutions at 0.05M. All showed a shrinkage or contraction amounting to 3–4 per cent. of the original thickness. The sections which were in $CaCl_2$ after the contraction began a slow expansion which continued during the 36 hours over which the observations were extended; the sections in NaCl remained inactive after the contraction during the same period, while those in KCl and in sea-water continued in a slow but steady and continuous shrinkage. It is evi-

dent, therefore, that this concentration of the salts is a critical one for this material whether fully hydrated or not.

When freshly cut sections with a water deficit which would cause an expansion of 150 to 160 per cent. in pure water were hydrated in salt solutions, the periods over which expansion extended in comparable series were as follows:

TABLE 6.

Solutions	KCl 0.01M.	NaCl 0.01M.	$CaCl_2$ 0.01–3M.
Duration of expansion	30 hours	48 hours	36 hours
Ionic velocity of kations	64.7	43.6	51.8

The relations between the action of potassium and sodium were illustrated by another series with shorter swelling periods in which the expansion of the sections in potassium extended over 24 hours and of those in sodium 32 hours. All of the above were at laboratory temperatures in which the liquids varied concurrently between 14° and 18° C.

The phenomena of expansion in "balanced" solutions of sodium are of interest in this connection. In a series in which full expansion in water was reached in 21 hours, this state was reached in NaCl 0.01 M in 23 hours, while the expansion in sea-water of an equivalent concentration of the Na reached full expansion in 27 hours, and in a 0.001 M solution of sea-water in 26 hours.

Simple balanced solutions of sodium with calcium in another series (Na 1 : Ca 50) gave larger ratios, full expansion in Na 0.01 M being reached in 19 hours and in the equivalent balanced solutions in 50 hours. At concentrations of 0.001 M satisfaction was reached in Na in 22 hours and in the balanced solution in 44 hours. It is notable that the increases in the sodium solutions were greater than in the equivalent simple balanced solutions, but that this relation was reversed when sea-water was used, the swellings in it being greater than the equivalent sodium solutions at all concentrations from 0.1 M to 0.001 M.

The following results were secured when sections of *Opuntia*

were hydrated in sodium solutions to which calcium in a 1 : 50 ratio had been added at 14°–20° C.:

TABLE 7.

Immersion Liquid	NaCl .01M.	NaCl .01M. CaCl .0002M.	NaCl .01M.	NaCl .001M. CaCl .00002M.
Percentage increase	156	145	150	142
Period before shrinking	10 hours	50 hours	22 hours	44 hours

A week later a similar series was carried through at 14°–20° C. in which sea-water in various dilutions was used as the balanced solution. The results were as follows:

TABLE 8.

Immersion Solutions	Sea-water	Sea-water 0.1M.	NaCl 0.1M.	Sea-water .01M.	NaCl .01M.	Sea-water .001M.	NaCl .001M.
Percentage increase	72	125	128	160	150	170	165
Hours before shrinkage	104	54	52	27	23	26	21

It would appear from the foregoing that the length of time during which increase in cell-masses takes place corresponds to the speed of the kations in the above experiments described. Satisfaction should be reached, therefore, earliest in the potassium, next in the calcium, and finally in the sodium. Stiles found that the initial rate of absorption of these kations from 0.01M solutions by potatoes and carrots followed this order, but that the final rate might reverse the position of Ca and Na.[5] These rates were determined by conductivity tests of the immersion liquids. All observers agree in the speedier and greater action of potassium in penetration or absorption, but some workers give the sodium and calcium alternate positions in the series. Some confusion also arises from the fact that initial and final rates of absorption are not distinguished and that total amount of absorption is taken as a direct index of rate.

It would also appear from the scanty data given above that ex-

[5] Stiles, W., and Kidd, F., "The Comparative Rate of Absorption of Salts by Plant Tissue," *Proc. Roy. Soc. B.*, 90, 488, 1919.

pansion is retarded in solutions of sodium when a small proportion of the same salt of calcium is present. This is also true when other substances, including magnesium, are present as in sea-water. As noted above, the living cell-masses in such solutions continue to expand for extended periods, presumably due to the lower rate of penetration of the sodium to which the swelling may be primarily attributed.

The relation between the total amounts of expansion and the total absorption of a kation is not so direct, however. Thus while Fitting placed the penetrability of calcium chloride very low, Stiles found that during the first hour of immersion that calcium chloride is absorbed at a much higher rate than sodium chloride, but this rate soon falls off. As concluded by Stiles, "the initial rate of absorption of salts is dependent to a great extent on the mobility of the ions or the coefficient of diffusion of the salt, but that the total intake of the salt depends on something other than this, as a result of which calcium, magnesium, and sulphate are absorbed to a much less extent than potassium, sodium, chloride, and nitrate."

Among the factors which have not been calibrated directly are to be included the extensibility of the wall and the changes in volume of the plasmatic mass. The limit of the extensibility of the wall reached in any solution of the salts used is determined by the aggregating or hydrating effect of the salt itself. In the present instance the greatest effect is produced by the calcium with some differences in the reactions of the material to sodium and potassium which may be attributed to the nature of the material, at medium concentrations. These facts are illustrated by the following measurements of expansion in sections of *Opuntia*:[6]

TABLE 9.

	KCl.	NaCl.	$CaCl_2$.	Water.
Immersion Liquids at 0.01M. Increase in percentage of original thickness	148	147	154	161
Immersion liquids at 0.05M. Increase in percentage of original thickness	145	140	160	168

[6] Fitting, H., "Untersuchungen ueber die Aufnahme von Salze in die lebende Zelle," *Jahrb. f. wiss. Bot.*, 56, 1–64, 1915.

These swellings were carried out at 16° to 18° C., but it is to be noted that the material in the two concentrations represent separate series and are not comparable with each other. Fair comparisons lie only in the data in each line.

The total expansion in all of the solutions is less than that in water, but is greatest in the solutions in which the greatest effect is exerted on the colloids—that is, in the solutions of calcium chloride. The aggregating effect of this substance on the colloids of the wall would render it less permeable to its own ions and to the cell-contents, including water. One evidence of this is in the comparatively small amount which is absorbed by the cell. Stiles found that the absorption ratio of calcium chloride was 1.09 as compared with that of potassium chloride at 3.59. The total expansion of cell-masses which had been rendered more permeable would be lessened or checked by the exosmosis which would occur as in sections immersed in potassium.

The reaction of dried slices of the above material are of some interest in the present connection. Joints which were 3.2 to 2.8 mm. in thickness were separated into two slices of half this thickness, each having an epidermal surface intact. Drying was brought about between thicknesses of filter paper with enough pressure applied to prevent curling. Two months later the slices, being brittle, were broken and cut into sections with a surface something less than that of the fresh sections. These were hydrated in the usual manner under the auxograph. The results are as below:

TABLE 10.

	KCl.	NaCl.	$CaCl_2$.	Seawater.	Water.
Immersion liquids at 0.01M. Increase in percentage of original thickness	310	280	275	310	255
Immersion liquids at 0.05M. Increase	270	270	220	244	

It is to be seen that the sections behave as inert colloids. The death of the cells has doubtless allowed the organic substances to escape through the external layers with their increased permeability, but the walls probably act to a slight extent as osmotically definite

membranes for these salts. Unlike the living cells, the amount of expansion is less at the higher concentration; the expansion is not definitely different in the living sections. Expansion is greatest in potassium in the weaker concentration in which the series would be parallel to that of swellings in agar, the similarity including the further fact that the increases were in excess of that in water.

It would, therefore, be reasonable to infer that in the living material the action of the cell-masses as osmometers is affected by changes in the permeability of the external layers and walls by which their osmotic action and consequent expansion or turgidity are modified by the action of the ions on the colloids. In the dried sections the osmotic action of the dead cell-sacs is probably very slight. It is more correctly to be taken as in accordance with the Hardy-Schulze law, which may be stated as follows: *Bases carrying a charge of opposite sign to that of a colloid exert a dehydrating or aggregating effect proportional to the unit charges which they carry.*

A still further feature is to be taken into consideration, that of the formation of definite compounds by the ions of the entering salts, the presence of which may alter the permeability of the cell in a very marked manner. The best illustration of this feature is the work of True dealing especially with the action of absorption and exosmosis from roots. His experiments in coöperation with Dr. Eckerson established the fact that calcium acting on the walls made them less readily permeable to potassium and to copper, and that a lesser interference was exerted by magnesium. Roots of wheat, maize, and lupines grown in solutions of potassium free from calcium were found to exude sugars, amino acids, and various salts. These facts are taken to rest wholly upon the diverse solubilities of the compounds formed by these bases with pectic acid derived from pectin, one of the pentosanic components of the wall, by the action of the enzyme pectase.[7]

That calcium pectate may form the external layer of the walls of root-hairs has been shown by Miss Howe;[8] it is generally known as

[7] True, R. H., "The Significance of Calcium for the Higher Green Plants," *Science*, 55, 1, 1922.

[8] Howe, Caroline G., "Pectic Material in Root-hairs," *Botan. Gazette*, 72, 313, 1922.

the main constituent of the middle lamella of joined cells. It is not probable that all of the pectin would be thus converted and some of it would remain in the jelly form subject to the aggregating or hydrating action of the kations. Something of the same condition exists with regard to the lipins of the wall and plasma, which may form compounds as well as aggregates with calcium and other bases.

Discussion.

Living cells and the type of artificial cell used in the experiments described in the present paper take up water from solutions in which they may be immersed by hydration of the colloids in the walls, and external layers, and by the osmotic action of the dissociated substances in the vacuolar fluids. Coincidentally with such action dissolved substances in the vacuole and in the immersion liquid tend to diffuse into and through the walls and plasmatic layers in opposite directions, at rates determined chiefly by their ionic mobility. It is generally assumed that the rate or amount of material which may diffuse into or out of the cell is but little affected or not at all by the osmotic movement of water through the external layers. The operation of the artificial cell yields results which show that the osmotic potential of a living cell, or the state of turgidity may have a very important influence on the absorption of materials from the medium.

The diffusion of the ions through the external layers of the cell is attended by absorptive unions when the ions meet colloidal particles of opposite sign, and by definite chemical unions under other circumstances. Either form or both forms of action may and does occur in the wall and plasmatic layers, with the result that their penetration by the ions of the common bases, potassium, sodium potassium, magnesium, etc., results in neutralizations, aggregations, precipitations, etc., which may materially modify the further passage of ions of the same material through the layers, but may also interfere in a positive manner with the diffusion of other ions. Lastly, the effect of such absorptive unions, aggregations, or combinations may be such as to make definite changes in the walls or external layers so that osmosis through them is modified. Substances dis-

solved in the vacuoles, such as sugars, organic acids, or salts, may pass by exosmosis out to the immersion liquid.

It naturally follows that no single series of calibrations may be made an index of proceedings so complex.

The increase in volume of living cells or of the cell-contents of the artificial cell employed in these experiments when placed in hypertonic solutions is due to the endosmotic action of the substances dissolved in the cell-sap or vacuolar fluids, mainly. The relative volume of the living cell is limited by the extensibility of its semi-rigid wall, which may be determined or modified by the entering ions.

The increase of the contents of the living cell is limited by the extensibility of the wall, which may be determined or modified by the action of the entering ions. If the cell is in a state of high turgidity when placed in the experimental solution, the modifying effect on the final stage of expansion may not be very great, yet it may be observed as it has been done by Kahho. If, on the other hand, the cell be taken in a condition in which it has a high water deficit, as was done with *Opuntia*, the total increase which may take place may be very great, and the relative effects of various dissolved substances in the immersion liquids stand out much more clearly. This is very obvious in the auxographic records of *Opuntia* taken at a season when living sections showed total swellings of 150 to 160 per cent. or even higher.

In any case, the immersion of living cells in solutions is a case in which various salts are already present in the external layers and walls. Unknown interferences may be encountered, and the exosmose and endosmose of material may not be so easily estimated. Furthermore, measurements of conductivity or resistance of such living cell-masses must be regarded as having been possibly modified by the presence of such organic substances as sugars, fatty acids, and amino acids.

The expansion of dried cell-masses are of a character which suggest a combination of osmotic action of the cell-sacs, which have become more permeable and less resistant by the loss of organic compounds, and of the hydration of colloids. The initial expansion is very rapid, followed by a long period of slow increase, the final col-

lapse not being so pronounced as in the hydration of living material. The action of the artificial cell when expressed in a graph makes a low or flattened "biological curve." This is indicative of external layers not readily permeable to salts or to organic compounds, similar to those of the living cell. The permeability of these layers are modifiable in the same manner in both the living and the artificial cell by the salts of the common bases.

Summary.

1. Changes in volume of living and dead cell-masses in various solutions have been recorded by the auxograph in experiments arranged to determine the effect of concentration and ionic mobility on permeability and hydration.

2. The amounts of endosmose in an artificial cell with external layers comprising the substances occurring in the relative positions in the living cell have been used as indices of the permeability of such layers. Such cells are constructed with walls of cellulose holding pentosans including pectins with an inner deposit of albumins and lipins and a plasmatic or retaining layer of pentosans.

3. The general amount of water absorbed by such cells is proportionate to the isomostic value of the cell-contents, which were solutions of sugar. The relative amounts absorbed when cells were immersed in salt solutions were found to correspond to the specific action of the ions of the salts on the colloids of the cell.

4. The ions of the salt solutions which penetrate the walls of the cell affect permeability of such colloids as the pentosans in a degree corresponding to their velocities, and in accordance with the Hardy-Schulze law. In addition, some of the bases form compounds with lipins, pectins, and albumins which affect permeability.

5. The conclusions of Kahho that antagonisms or interferences are the result of the relative action of different ions; the more active an ion may be on colloids, the less is its capacity for penetration of the colloid are supported. Thus potassium shows a high rate of penetration and a lesser colloidal action than calcium which has a high aggregating effect on colloids and a low power of penetration.

6. The rate of endosmose in the artificial cell increases as permeability is lessened. The series which effects a lessening permeability in the order named, according to Troendle, K, Na, Ca is shown by artificial cells with external layers of lipin, pectin, and other pentosans. The inclusion of an albuminous component in the cell results in an exaggeration of the effect of Na.

7. Conductivity tests show that cells including an albuminous component show the greatest absorption of ions from a calcium salt solution and the least from a sodium salt solution with the rate in a potassium salt solution lying between these two.

8. Conductivity tests of cell-contents show that the abundance of the above-named bases in a decreasing series would be K, Ca, and Na in the albuminous cell. A disproportionate amount of sodium is taken from the immersion liquid, which does not pass into the cell-contents and must therefore be absorbed by the material of the external layers or combined with some of its components, probably the gelatine.

9. Sections of *Opuntia* immersed in salt solutions showed a slight contraction at concentrations of 0.05M in KCl, NaCl, and $CaCl_2$ and in sea-water at 0.06M. This contraction was recovered in this and in concentrations as high as 0.18M KCl, 0.14M NaCl, and 0.07M $CaCl_2$. These concentrations are approximately isotonic and represent the solution which will plasmolyze this material.

10. The length of the period in which living cell-masses of *Opuntia* reached full expansion in salt solutions at 0.01 and 0.05M is proportionate to the ionic velocity of the salts, the sequence of the common bases being KCl, $CaCl_2$, and NaCl, in which the time of expansion is shortest in the K and longest in the Na solution.

11. The period of expansion in sodium solutions is much less in the pure solution than it is in a balanced solution in which the calcium is one fiftieth of the sodium. A similar difference is found when sea-water is used as the balanced solution.

12. Dried sections of *Opuntia* react chiefly as colloidal material and in accordance with the Hardy-Schulze law by which "bases carrying a charge of opposite sign to that of a colloid exert a dehydrating or aggregating effect proportional to the unit charges they

carry." The hydration swelling of this material in solutions at 0.01 M gives a decreasing series which is K, sea-water, Na, Ca.

13. The expansion coefficients of living material in salt solutions includes osmotic effects and perhaps those of chemical combinations so that the decreasing series is Ca, K, Na, the greatest expansion being in cells with the least permeable walls, in which, of course, the highest turgidity may be set up.

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SOME APPLICATIONS OF HEAVISIDE'S OPERATIONAL METHODS.

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1. Although the operational methods devised by Heaviside for getting solutions of the partial differential equations of physics have received some attention recently,[1] they do not appear to be as generally known as they deserve to be. These methods are particularly well adapted to obtaining the normal expansions required for the solution of many problems; many of these may be obtained by setting up artificial, although physically possible, problems, and the expansions result almost automatically. A number of illustrations will be given in this paper; the problems selected are those which involve more than one independent variable, besides the time.

In these applications, use is made of Heaviside's Expansion Theorem, which may be stated as follows:

Denoting the operator $\partial/\partial t$ by p, and assuming that the solution of the differential equation, satisfying the boundary conditions, can be obtained in the operational form

$$v = \frac{Y(p)}{Z(p)} v_0, \tag{1.1}$$

where v_0 is a constant, then the solution of the problem is

$$v = v_0 \left\{ \frac{Y(0)}{Z(0)} + \sum_{m=1}^{\infty} \frac{Y(p_m)}{p_m Z'(p_m)} \epsilon^{p_m t} \right\}. \tag{1.2}$$

[1] These methods are described and illustrated by many applications in Heaviside's Electromagnetic Theory, Volumes II. and III. His Electrical Papers, Vols. I. and II., also contain many references to these methods and show how he was led to formulate them. For additional details regarding these methods, reference may be made to the following papers: Bromwich, *Proc. London Math. Soc.*, 15, 1916, p. 401; *Phil. Mag.*, 38, 1919, p. 407; *Proc. Cambridge Phil. Soc.*, 20, 1920, p. 411. Carson, *Physical Review*, 10, 1917, p. 217. Herlitz, *Arkiv fur Matematik, Astronomi och Fysik*, Band 14, No. 22, 1919.

where the p_m denote the real roots of $Z(p) = 0$ in ascending order of magnitude, and the summation is to be taken over all the real roots, except zero. This solution makes $v = 0$ at $t = 0$.

2. The first problem considered is that of the distribution of temperature in a wire of circular section, carrying a steady electric current, at any time after the current begins to flow. The two ends of the wire are kept at a temperature $v = 0$, and radiation is supposed to take place from the lateral surface of the wire into the medium, at temperature $v = 0$, so that the amount of energy radiated from unit surface, in unit time, is proportional to its temperature.

Let l be the length of the wire, and a the radius of its cross-section; k the thermal conductivity, c the specific heat, and ρ the density. Let H be the heat generated in unit volume and unit time by the electric current. By considering a tube of length dx, internal radius r, and wall thickness dr, the partial differential equation may be written

$$\frac{\partial^2 v}{\partial x^2} + \frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial v}{\partial r}\right) - \frac{1}{\kappa}\frac{\partial v}{\partial t} + w = 0, \qquad 2.1$$

where $\kappa = k/c\rho$, and $w = H/k$. The boundary conditions are

$$v = 0, \text{ at } x = 0 \text{ and at } x = l, \qquad 2.2$$

$$-k\frac{\partial v}{\partial r} = hv \text{ at } r = a, \qquad 2.3$$

where h is the emissivity, or exterior conductivity. At $t = 0$, the whole wire is at temperature $v = 0$.

Before proceeding to the general solution, it will be convenient to consider first two special cases, no radial temperature gradient, and no longitudinal temperature gradient.

3. No Radial Temperature Gradient. In this special case it is necessary to write the condition at $r = a$ into the differential equation, with the result

$$\frac{\partial^2 v}{\partial x^2} - \frac{2h}{ak}v + w - \frac{1}{\kappa}\frac{\partial v}{\partial t} = 0. \qquad 3.1$$

With

$$\lambda^2 = \frac{2h}{ak}, \quad \frac{\partial}{\partial t} = p, \quad \text{and} \quad \lambda^2 + \frac{p}{\kappa} = q^2,$$

the differential equation becomes

$$\frac{\partial^2 v}{\partial x^2} = q^2 v - w, \qquad 3.2$$

and its complete solution is

$$v = \epsilon^{qx} A + \epsilon^{-qx} B + \frac{w}{q^2},$$

where A and B are constants; determining them by the condition 2.2, we get

$$v = \frac{\sinh q(x - l) - \sinh qx + \sinh ql}{q^2 \sinh ql} w,$$

or writing $s^2 = -q^2$,

$$v = \frac{\sin s(x - l) - \sin sx + \sin sl}{s^2 \sin sl} w.$$

This equation is of the form 1.1 and we can apply the expansion theorem to it directly. The roots of $Z = 0$, or $s^2 \sin sl = 0$, are $s = n\pi/l$, where n is any integer. With $Z = s^2 \sin sl$, we have

$$p\frac{dZ}{dp} = \frac{n\pi}{2}(-1)^n \left(\lambda^2 + \frac{n^2\pi^2}{l^2}\right).$$

and with the values given for s,

$$Y = \sin s(x - l) - \sin sx + \sin sl = -\{1 - (-1)^n\} \sin \frac{n\pi x}{l}.$$

When $p = 0$, $q = \lambda$, and therefore

$$\begin{aligned}\frac{Y(0)}{Z(0)} &= w\frac{\sinh \lambda(x - l) - \sinh \lambda x + \sinh \lambda l}{\lambda^2 \sinh \lambda l} \\ &= \frac{w}{\lambda^2}\left\{1 - \frac{e^{\lambda x} + e^{\lambda(l-x)}}{1 + e^{\lambda l}}\right\}.\end{aligned}$$

The complete solution, for the case of no radial temperature gradient, may therefore be written

$$v_t = \frac{w}{\lambda^2}\left\{1 - \frac{e^{\lambda x} + e^{\lambda(l-x)}}{1 + e^{\lambda l}} - 4\sum_{n=1}^{\infty} \frac{\sin (2n - 1)\frac{\pi x}{l} \exp. - \kappa\left\{\lambda^2 + (2n - 1)^2\frac{\pi^2}{l^2}\right\}t}{(2n - 1)\pi\left\{1 + \frac{(2n - 1)^2\pi^2}{l^2\lambda^2}\right\}}\right\}. \qquad 3.3$$

As this solution must reduce to $v_1 = 0$ when $t = 0$, we find the Fourier expansion

$$1 - \frac{e^{\lambda x} + e^{\lambda(l-x)}}{1 + e^{\lambda l}} = 4\sum_{n=1}^{\infty} \frac{\sin (2n-1)\dfrac{\pi x}{l}}{(2n-1)\pi\left\{1 + (2n-1)^2\dfrac{\pi^2}{l^2\lambda^2}\right\}}, \quad 3.4$$

valid for $0 \leq x \leq l$; this may be verified directly.

4. No Longitudinal Temperature Gradient. In this case the differential equation 2.1 becomes

$$\frac{\partial^2 v}{\partial r^2} + \frac{1}{r}\frac{\partial v}{\partial r} + q^2 v = -w \quad 4.1$$

with $q^2 = -p/\kappa$. The solution of this equation, satisfying the condition of remaining finite at $r = 0$, is

$$v = J_0(qr)A - \frac{w}{q^2},$$

where A is a constant, and J_0 is the Bessel function of order 0. At $r = a$ the boundary condition 2.3 leads to

$$A = \frac{wh}{q^2\{hJ_0(qa) - kqJ_1(qa)\}},$$

using the relation $J_0'(x) = -J_1(x)$. The symbolic solution of the problem, corresponding to 1.1, is therefore

$$v = \frac{hJ_0(qr) - hJ_0(qa) + kqJ_1(qa)}{q^2\{hJ_0(qa) - kqJ_1(qa)\}}w.$$

When $p = 0$, $q = 0$, and using the first terms in the series,

$$J_0(x) = 1 - \frac{x^2}{4} + \cdots,$$

$$J_1(x) = \frac{x}{2} - \cdots,$$

we find

$$\frac{Y(0)}{Z(0)} = w\left\{\frac{ak}{2h} + \frac{1}{4}(a^2 - r^2)\right\},$$

the temperature at $t = \infty$, or $p = 0$.

The roots of

$$Z = q^2\{hJ_0(qa) - kqJ_1(qa)\} = 0$$

are the roots of

$$bxJ_1(x) = J_0(x), \qquad 4.2$$

where

$$b = \frac{k}{ah}. \qquad 4.3$$

It is known that the roots of this equation are all real.[2] Denoting these roots by α_n, we have, for the permissible values of q,

$$q^2 = \frac{\alpha_n^2}{a^2} = -\frac{p_n}{\kappa}.$$

Making use of the differential equation satisfied by $J_0(qa)$, we find for the values of $p(dZ/dp)$, with these roots,

$$p\frac{dZ}{dp} = -\frac{k\alpha_n^2}{2a}\left(\frac{\alpha_n^2}{a^2} + \frac{h^2}{k^2}\right)J_0(\alpha_n)$$

and the complete solution, for the case of no longitudinal temperature gradient, is

$$v_2 = wa^2\left\{\frac{b}{2} + \frac{1}{4} - \frac{1}{4}\frac{r^2}{a^2} - 2b\sum_{n=1}^{\infty}\frac{J_0\left(\frac{\alpha_n}{a}r\right)\exp. -\kappa\frac{\alpha_n^2}{a^2}t}{\alpha_n^2(b^2\alpha_n^2+1)J_0(\alpha_n)}\right\}. \qquad 4.4$$

Since for $t = 0$, $v = 0$, we have the expansion, writing $r/a = x$,

$$\frac{b}{2} + \frac{1}{4} - \frac{1}{4}x^2 = 2b\sum_{n=1}^{\infty}\frac{J_0(\alpha_n x)}{\alpha_n^2(b^2\alpha_n^2+1)J_0(\alpha_n)}, \qquad 4.5$$

valid for $0 \leq x \leq 1$. This result can be obtained directly, using the Dini expansion in Bessel Functions.[3]

5. The general case, where there is both a radial and a longitudinal temperature gradient, will now be considered. Assume a solution of 2.1 in the form

$$v = RX + R_1,$$

where R and R_1 are functions of r only, and X a function of x only; and then taking $R_1 = v_2$, given by 4.4, which is a solution of 4.1, we find that R and X must be solutions of the differential equation

$$R\frac{\partial^2 X}{\partial x^2} + X\frac{\partial^2 R}{\partial r^2} + \frac{X}{r}\frac{\partial R}{\partial r} - \frac{p}{\kappa}RX = 0.$$

[2] Gray and Mathews, "Bessel Functions," 2d edition, p. 83.

[3] Watson, "Bessel Functions," p. 596.

On separating the variables, this leads to the two equations

$$\frac{\partial^2 R}{\partial r^2} + \frac{1}{r}\frac{\partial R}{\partial r} + \beta^2 R = 0, \qquad 5.1$$

$$\frac{\partial^2 X}{\partial x^2} = \left(\frac{p}{\kappa} + \beta^2\right) X, \qquad 5.2$$

where β^2 is a constant. The solution of 5.1 is

$$R = AJ_0(\beta r),$$

and writing

$$\frac{p}{\kappa} + \beta^2 = q^2, \qquad 5.3$$

the solution of 5.2 is

$$X = Be^{qx} + Ce^{-qx}.$$

Since the temperature must be the same at equal distances from the two ends, we can write

$$X = B(e^{qx} + e^{q(l-x)}).$$

We thus arrive at the symbolic solution of the problem

$$v = ABJ_0(\beta r)\{e^{qx} + e^{q(l-x)}\} + v_2,$$

where v_2, given by 4.4, satisfies the boundary condition at $r = a$. In order that the first term, also, may satisfy this condition, it is necessary that βa be a root of the equation 4.2. Then the permissible values of β are given by

$$\beta = \frac{\alpha_n}{a}.$$

One of the two constants, A and B, may be chosen arbitrarily; in order to make $v = 0$ at $x = 0$ and at $x = l$ in the steady state, choose

$$B = -\frac{1}{1 + e^{ql}}.$$

In the steady state, $p = 0$, $q = \beta = \alpha_n/a$, and we have, at $x = 0$ and at $x = l$,

$$\sum A_n J_0\left(\frac{\alpha_n}{a} r\right) = w\left\{\frac{ak}{2h} + \frac{1}{4}(a^2 - r^2)\right\}.$$

By comparison with 4.5 we see that the constants A_n are given by

$$A_n = \frac{2ahw}{k}\frac{1}{\alpha_n^2\left(\frac{\alpha_n^2}{a^2}+\frac{h^2}{k^2}\right)J_0(\alpha_n)}.$$

We now apply the expansion theorem, 1.2, to

$$\frac{Y(p)}{Z(p)} = \frac{e^{qz}+e^{q(l-z)}}{1+e^{ql}}.$$

This gives

$$\frac{e^{qz}+e^{q(l-z)}}{1+e^{ql}} = \frac{e^{\frac{\alpha_n}{a}z}+e^{\frac{\alpha_n}{a}(l-z)}}{1+e^{\frac{\alpha_n}{a}l}}$$

$$-\frac{4\pi}{l^2}\sum_{m=1}^{\infty}\frac{(2m-1)\sin(2m-1)\frac{\pi x}{l}}{\frac{\alpha_n^2}{a^2}+(2m-1)^2\frac{\pi^2}{l^2}}$$

$$\times \exp. -\kappa\left\{\frac{\alpha_n^2}{a^2}+(2m-1)^2\frac{\pi^2}{l^2}\right\}t. \qquad 5.4$$

For the final solution of the general case, we find

$$v = w\left\{\frac{ka}{2h}+\frac{1}{4}(a^2-r^2)\right\}$$

$$-\frac{2ahw}{k}\sum_{n=1}^{\infty}\frac{J_0\left(\frac{\alpha_n}{a}r\right)}{\alpha_n^2\left\{\frac{\alpha_n^2}{a^2}+\frac{h^2}{k^2}\right\}J_0(\alpha_n)}\left\{\frac{e^{\frac{\alpha_n}{a}z}+e^{\frac{\alpha_n}{a}(l-z)}}{1+e^{\frac{\alpha_n}{a}l}}\right.$$

$$+e^{-\kappa\frac{\alpha_n^2}{a^2}t}-\frac{4\pi}{l^2}\sum_{m=1}^{\infty}\frac{(2m-1)\sin(2m-1)\frac{\pi x}{l}}{\frac{\alpha_n^2}{a^2}+(2m-1)^2\frac{\pi^2}{l^2}} \qquad 5.5$$

$$\left.\times \exp. -\kappa\left\{\frac{\alpha_n^2}{a^2}+(2m-1)^2\frac{\pi^2}{l^2}\right\}t\right\}.$$

Since $v = 0$ when $t = 0$, we see by means of the expansion 4.5 that

$$\frac{e^{\frac{\alpha_n}{a}z}+e^{\frac{\alpha_n}{a}(l-z)}}{1+e^{\frac{\alpha_n}{a}l}} = \frac{4\pi}{l^2}\sum_{m=1}^{\infty}\frac{(2m-1)\sin(2m-1)\frac{\pi x}{l}}{\left\{\frac{\alpha_n^2}{a^2}+(2m-1)^2\frac{\pi^2}{l^2}\right\}}. \qquad 5.6$$

This also comes from 5.4, putting $t = 0$. This Fourier expansion may easily be obtained directly, and is valid for $0 < x < l$, but not at the limits. Therefore the conditions at the two ends of the wire are not satisfied by this solution initially; the reason for this lies in the assumption made that the electric current attains its steady value instantaneously, which, of course, is impossible.

6. After the steady state is reached, the whole amount of energy radiated from the wire in unit time is

$$W = 2\pi ah \int_0^l v_a dx,$$

where v_a is the temperature at $r = a$. This gives, when both radial and longitudinal temperature gradients are considered,

$$W = \pi wka^2l - \frac{8\pi a^3h^2w}{k}\sum_{n=1}^{\infty}\frac{e^{\frac{\alpha_n}{a}l} - 1}{e^{\frac{\alpha_n}{a}l} + 1}\,\frac{1}{\alpha_n^3\left(\dfrac{\alpha_n^2}{a^2} + \dfrac{h^2}{k^2}\right)}.$$

Neglecting the longitudinal temperature gradient, we would have

$$W_2 = \pi a^2wkl = \pi a^2lH,$$

which is equal to the whole amount of heat generated in the wire in unit time. Neglecting the radial temperature gradient, we would have

$$W_1 = \pi wka^2l - 2\pi a^2wk\sqrt{\frac{ak}{2h}}\left\{\frac{\exp.\left\{l\sqrt{\dfrac{2h}{ak}}\right\} - 1}{\exp.\left\{l\sqrt{\dfrac{2h}{ak}}\right\} + 1}\right\}.$$

If, in the general expression for W, we take only the first term in the infinite series, assume that h/k may be neglected in comparison with α_1/a, and take $\alpha_1 = \sqrt{(2ha/k)}$, we get the same expression for the total heat radiated as is given by neglecting the radial temperature gradient. We thus have the result that when b is large, the first root of

$$bxJ_1(x) = J_0(x)$$

is given approximately by $\sqrt{(2/b)}$. How large b must be in order

that this relation may be satisfied may be seen from the following table:

b	a_1	$\sqrt{(2/b)}$
1	1.256	1.414
10	0.442	0.447
100	0.141	0.1414

From this it appears that if $b = k/ah$ is as large as 10, the error in neglecting the radial temperature gradient is small.

7. The next problem considered is that of a sphere, exposed to radiation from one side, so that over half the surface of the sphere the radiation received on unit surface in unit time is $\epsilon \cos \theta$. The angle θ is measured from the axis of the hemisphere receiving the radiation. The whole surface of the sphere is supposed to radiate energy into the medium at the rate hv per unit area, v being the temperature of the surface.

The differential equation of the conduction of heat in spherical polar coördinates, when there is symmetry about the axis, is

$$\frac{1}{r^2}\frac{\partial}{\partial r}\left(r\frac{\partial v}{\partial r}\right) + \frac{1}{r^2 \sin\theta}\frac{\partial}{\partial \theta}\left(\sin\theta\frac{\partial v}{\partial \theta}\right) + q^2 v = 0, \qquad 7.1$$

where $p = \partial/\partial t$, $\kappa = k/c\rho$, and $q^2 = p/\kappa$.

Assume a solution $v = R\Theta$, where R is a function of r only, and Θ a function of θ only. Separating the variables, the equation breaks down into the two equations

$$\frac{\partial^2 R}{\partial r^2} + \frac{2}{r}\frac{\partial R}{\partial r} + \left\{ q^2 - \frac{n(n+1)}{r^2} \right\} R = 0, \qquad 7.2$$

$$\frac{1}{\sin\theta}\frac{\partial}{\partial\theta}\left(\sin\theta\frac{\partial\Theta}{\partial\theta}\right) + n(n+1)\Theta = 0. \qquad 7.3$$

n can have only integral values.

The solution of 7.2 is[4]

$$R = S_n(qr),$$

where

$$S_n(x) = x^n \left\{ \frac{1}{x}\frac{\partial}{\partial x} \right\}^n \frac{\sin x}{x}$$

This solution remains finite at $r = 0$. 7.3 is Legendre's equation,

[4] J. J. Thomson, "Recent Researches in Electricity and Magnetism," p. 363.

and its solution is

$$\Theta = P_n(\cos\theta).$$

Therefore,

$$v = \sum A_n P_n(\cos\theta) S_n(qr).$$

The boundary condition at $r = a$ is

$$-k\frac{\partial v}{\partial r} = hv - \epsilon f(\theta),$$

where

$$\begin{aligned} f(\theta) &= \cos\theta \text{ for } -\pi/2 \leq \theta \leq +\pi/2 \\ &= 0 \text{ for } \pi/2 \leq \theta \leq 3\pi/2. \end{aligned}$$

We now develop $f(\theta)$ in an infinite series of zonal harmonics, so as to satisfy these conditions. Writing $\cos\theta = \mu$, we have

$$f(\theta) = \sum_{n=0}^{\infty} B_n P_n(\mu),$$

where

$$B_n = \frac{2n+1}{2}\int_0^1 \mu P_n(\mu)d\mu.$$

The first few coefficients, B_n, are thus found, as follows:

$$\left.\begin{aligned} B_0 &= \frac{1}{4}, & B_4 &= -\frac{3}{32}, \\ B_1 &= \frac{1}{2}, & B_6 &= \frac{13}{256}, \\ B_2 &= \frac{5}{16}, & B_8 &= -\frac{17}{512}, \end{aligned}\right\} \qquad 7.4$$

$$B_3 = B_5 = B_7 = \cdots = 0.$$

Then, at $r = a$,

$$k\sum_{n=0}^{\infty} A_n\{qS_n'(qa) + hS_n(qa)\}P_n(\mu) = \epsilon\sum_{n=0}^{\infty} B_n P_n(\mu).$$

Equating the coefficients of $P_n(\mu)$ on the two sides of this equation,

$$A_n = \frac{\epsilon B_n}{kqS_n'(qa) + hS_n(qa)},$$

and the symbolic solution of the problem, corresponding to 1.1, is

$$v = \frac{\epsilon}{h}\sum_{n=0}^{\infty}\frac{B_n S_n(qr) P_n(\cos\theta)}{b\cdot qaS_n'(qa) + S_n(qa)},$$

where $b = k/ah$, and the numerical coefficients, B_n, are given by 7.4.

We now apply the expansion theorem to each term of the infinite series in the operational solution. $S_n(x)$ and $S_n'(x)$ are given by the series

$$S_n(x) = (-1)^n \frac{x^n}{1\cdot 3\cdot 5\cdots(2n+1)} + \cdots,$$

$$S_n'(x) = (-1)^n \frac{nx^{n-1}}{1\cdot 3\cdot 5\cdots(2n+1)} + \cdots.$$

When $p = 0$, $q = 0$, and using the first terms in these series, we find, for $p = 0$,

$$\frac{S_n(qr)}{b\cdot qaS_n'(qa) + S_n(qa)} = \left(\frac{r}{a}\right)^n \frac{1}{1 + nb}.$$

The roots of the equation

$$Z = b\cdot qaS_n'(qa) + S_n(qa) = 0$$

are the roots of

$$bxS_n'(x) + S_n(x) = 0.$$

Denote these roots by $\alpha_{m,n}$. Then the permissible values of p are

$$p_m = -\kappa\frac{\alpha_{m,n}^2}{a^2}.$$

Since $p = -\kappa q^2$, we find, using the differential equation satisfied by $S_n(qa)$,

$$p\frac{dZ}{dp} = -\frac{1}{2b}\{1 - b + b^2q^2a^2 - b^2n(n+1)\}S_n(qa).$$

The complete solution of the problem is, therefore,

$$v = \frac{\epsilon}{h}\sum_{n=0}^{\infty} B_n P_n(\cos\theta)\left\{\frac{1}{1+nb}\left(\frac{r}{a}\right)^n \right.$$

$$\left. - 2b\sum_{m=1}^{\infty}\frac{S_n\left(\frac{\alpha_{m,n}}{a}r\right)\exp.\left\{-\kappa\frac{\alpha_{m,n}^2}{a^2}t\right\}}{\{1 - b + b^2\alpha_{m,n}^2 - b^2n(n+1)\}S_n(\alpha_{m,n})}\right\}. \qquad 7.6$$

8. Instead of using the S_n functions, we may use the Bessel functions of order half an odd integer. The relations between these

functions are

$$S_n(x) = (-1)^n \sqrt{\frac{\pi}{2x}} J_{\frac{2n+1}{2}}(x),$$

$$S_n'(x) = (-1)^n \sqrt{\frac{\pi}{2x}} \left\{ \frac{n}{x} J_{\frac{2n+1}{2}}(x) - J_{\frac{2n+3}{2}}(x) \right\},$$

and the $\alpha_{m,n}$ are the roots of

$$(1 + bn) J_{\frac{2n+1}{2}}(x) = bx J_{\frac{2n+3}{2}}(x).$$

As $v = 0$ at $t = 0$, we get the expansion, writing $x = r/a$,

$$x^{\frac{2n+1}{2}} = 2b(1 + nb) \sum_{m=1}^{\infty} \frac{J_{\frac{2n+1}{2}}(\alpha_{m,n} x)}{\{1 - b + b^2\alpha_{mn}^2 - b^2 n(n+1)\} J_{\frac{2n+1}{2}}(\alpha_{m,n})},$$

valid for $0 \leq x \leq 1$, but only for positive values of b, since only these have any physical significance. This expansion has been obtained for even integral values of n, as well as $n = 0$ and $n = 1$, only; but by making the assumption that the energy falling on half the sphere is equal to $\epsilon \cos^2 \theta$ per unit area in unit time, the same expansion may be obtained for odd values of n. These same expansions may be obtained from the Dini expansions in Bessel functions, and can be shown to be valid for all values of $n > -1$, whether integral or not. Taking, in particular, $x = 1$, and $b = 1/(n + 1)$, we have

$$\frac{1}{4n + 2} = \sum_{m=1}^{\infty} \frac{1}{\alpha_{m,n}^2},$$

where $\alpha_{m,n}$ are the roots of

$$(2n + 1) J_{\frac{2n+1}{2}}(x) = x J_{\frac{2n+3}{2}}(x),$$

or the zeros of $J_{(2n-1)/2}(x)$. This is a known result.[5] For $n = 2$, the $\alpha_{m,2}$ are the roots of $\tan x = x$, and it follows that the sum of the squares of the reciprocals of all the roots (except 0) of $\tan x = x$ is equal to $1/10$. Many other results of this nature may be obtained from these expansions.

For the temperature of the center of the sphere, at any time, t,

[5] Watson, l.c., p. 502. Lord Rayleigh, Scientific Papers, Vol. I., p. 190.

after the radiation begins to fall upon it, we get

$$v = \frac{\epsilon}{4h}\left\{1 - 2b\sum_{m=1}^{\infty}\frac{\alpha_{m,0}\exp.\left\{-\kappa\frac{\alpha_{m,0}^2}{a^2}t\right\}}{(1-b+b^2\alpha_{m,0}^2)\sin\alpha_{m,0}}\right\},$$

where the $\alpha_{m,0}$ are the roots (except 0) of

$$\tan x = \frac{bx}{b-1}.$$

For a sphere of such material and radius that $b = 1$, this expression takes the simple form

$$v = \frac{\epsilon}{4h}\left\{1 + \frac{4}{\pi}\sum_{m=1}^{\infty}\frac{(-1)^m}{2m-1}\exp.\left\{-\kappa(2m-1)^2\frac{\pi^2 t}{4a^2}\right\}\right\}.$$

9. A problem similar to the last one is that of an infinitely long cylinder which receives radiation from one side. The differential equation to be solved is, in cylindrical coördinates,

$$\frac{\partial^2 v}{\partial r^2} + \frac{1}{r}\frac{\partial v}{\partial r} + \frac{1}{r^2}\frac{\partial^2 v}{\partial \theta^2} + q^2 v = 0,$$

where $p = -\kappa q^2$. Separating the variables, as before, we find

$$v = \sum_{n=0}^{\infty} J_n(qr)\{A_n \sin n\theta + B_n \cos n\theta\}.$$

At $r = a$, the radius of the cylinder, the boundary condition is

$$-k\frac{\partial v}{\partial r} = hv - \epsilon f(\theta),$$

where

$$\begin{aligned} f(\theta) &= \cos\theta \text{ for } -\pi/2 \leq \theta \leq +\pi/2 \\ &= 0 \text{ for } +\pi/2 \leq \theta \leq 3\pi/2. \end{aligned}$$

The corresponding Fourier expansion is easily found to be

$$f(\theta) = \sum_{n=0}^{\infty} c_n \cos n\theta, \qquad 9.1$$

where

$$\left.\begin{aligned} c_0 &= 1/\pi, \\ c_1 &= 1/2, \\ c_{2n+1} &= 0, \\ c_{2n} &= (-1)^{n+1}\frac{2}{(4n^2-1)\pi}. \end{aligned}\right\} \qquad 9.2$$

The surface condition thus leads to the symbolic solution

$$v = \frac{\epsilon}{h}\sum_{n=1}^{\infty}\frac{c_n J_n(qr)\cos n\theta}{b\cdot qaJ_n'(qa) + J_n(qa)},$$

where $b = k/ah$, and the numerical coefficients c_n are given by 9.2. Finally, by applying the expansion theorem to each term of this infinite series, the complete solution is found to be

$$v = \frac{\epsilon}{h}\sum_{n=0}^{\infty} c_n \cos n\theta \left\{ \frac{1}{1 + nb}\left(\frac{r}{a}\right)^n - \sum_{m=1}^{\infty}\frac{2bJ_n\left(\frac{\alpha_{m,n}}{a}r\right)\exp.\left\{-\frac{\kappa}{a^2}\alpha_{mn}^2 t\right\}}{(b^2\alpha_{m,n}^2 - b^2n^2 + 1)J_n(\alpha_{m,n})}\right\}, \qquad 9.3$$

where the $\alpha_{m,n}$ are the roots of

$$\left.\begin{aligned} &bxJ_n'(x) + J_n(x) = 0, \\ \text{or of}\quad &(1 + bn)J_n(x) = bxJ_{n+1}(x). \end{aligned}\right\} \qquad 9.4$$

As $v = 0$ initially, the expansion results

$$\frac{1}{2b(1 + nb)}x^n = \sum_{m=1}^{\infty}\frac{J_n(\alpha_{m,n}x)}{(b^2\alpha_{m,n}^2 - b^2n^2 + 1)J_n(\alpha_{m,n})}, \qquad 9.5$$

valid for $0 \leq x \leq 1$, and for all positive values of b. This has been found only for even values of n, with $n = 0$ and $n = 1$ in addition; but by assuming the incident radiation on half the cylindrical surface to be $\epsilon \cos^2\theta$ the same expansion would result for odd values of n. And the Dini expansion theorem shows that this is valid for all values of $n > 1/2$, integral or not.

10. A finite circular cylinder, exposed to uniform radiation over one base, will next be considered. The differential equation, in cylindrical coördinates, is

$$\frac{\partial^2 v}{\partial r^2} + \frac{1}{r}\frac{\partial v}{\partial r} + \frac{\partial^2 v}{\partial z^2} + q^2 v = 0,$$

with $p = -\kappa q^2$. By symmetry, v must be independent of θ; z is measured along the axis of the cylinder, height $2l$, radius a, with the origin at the center. Separating the variables, by assuming

a solution of the form $v = RZ$, where R, Z depend only on r, z respectively, we get

$$v = \sum J_0(\lambda r)\{Ae^{\sqrt{\lambda^2-q^2}z} + Be^{-\sqrt{\lambda^2-q^2}z}\},$$

where the summation is over all the permissible values of λ to be determined by the boundary conditions. These boundary conditions are

$$\text{At } z = +l, \qquad -k\frac{\partial v}{\partial z} = hv - \epsilon,$$

$$z = -l, \qquad k\frac{\partial v}{\partial z} = hv,$$

$$r = a, \qquad -k\frac{\partial v}{\partial r} = hv.$$

From the condition at $z = -l$ we find

$$B = Ae^{-l\sqrt{\lambda^2-q^2}}\frac{k\sqrt{\lambda^2 - q^2} - h}{k\sqrt{\lambda^2 - q^2} + h}. \qquad 10.1$$

To satisfy the condition at $r = a$, we must have

$$b\cdot\lambda a J_1(\lambda a) = J_0(\lambda a), \qquad 10.2$$

where $b = k/ha$. Denoting the roots of this equation by α_m we have for the permissible values of λ,

$$\lambda_m = \alpha_m/a.$$

In order to satisfy the condition at $z = +l$, we must express the constant, ϵ, as a Dini series in $J_0(\alpha_m r/a)$, where α_m is any root of 10.2; these roots are the same as the roots of 9.4 for $n = 0$. Therefore the required series is obtained by putting $n = 0$ in 9.3,

$$\epsilon = 2b\epsilon\sum_{m=1}^{\infty}\frac{J_0\left(\dfrac{\alpha_m}{a}r\right)}{(b^2\alpha_m^2 + 1)J_0(\alpha_m)},$$

where α_m has been written for $\alpha_{m,0}$. So, at $z = +l$, we have

$$k\sigma_m\{Ae^{\sigma_m l} - Be^{-\sigma_m l}\} + h\{Ae^{\sigma_m l} + Be^{-\sigma_m l}\} = \frac{2\epsilon b}{(b^2\alpha_m^2 + 1)J_0(\alpha_m)},$$

where

$$\sigma_m^2 = \lambda_m^2 - q^2 = \frac{\alpha_m^2}{a^2} - q^2.$$

Combining this equation with 10.1 A and B are determined, and the symbolic solution of the problem is

$$v = 2\epsilon b\sum_{m=1}^{\infty}\frac{(k\sigma_m + h)e^{\sigma_m(z+l)} + (k\sigma_m - h)e^{-\sigma_m(z+l)}}{e^{2\sigma_m l}(k\sigma_m + h)^2 - e^{-2\sigma_m l}(k\sigma_m - h)^2}\frac{J_0(\lambda_m r)}{(b^2\alpha_m^2+1)J_0(\alpha_m)}\cdot$$

For the final state, we must put $p = 0$, $q^2 = 0$, $\lambda_m = \alpha_m/a$, where the α_m are the roots of

$$bxJ_1(x) = J_0(x). \qquad 10.3$$

We now apply the expansion theorem to each term of the infinite series in the symbolic solution. The roots of

$$Z = e^{2\sigma_m l}(k\sigma_m + h)^2 - e^{-2\sigma_m l}(k\sigma_m - h)^2 = 0$$

are the roots of

$$k\sigma \sinh \sigma l = - h \cosh \sigma l,$$

or writing

$$\beta = i\sigma,$$

the roots of $Z = 0$ are the roots of

$$\tan \beta l = \frac{h}{k\beta}\cdot \qquad 10.4$$

Denoting these roots, which are all real, and infinite in number, by β_n, we have for the permissible values of p,

$$p_n = -\left(\beta_n^2 + \frac{\alpha_m^2}{a^2}\right)\kappa.$$

For these values of p, we find

$$p\frac{dZ}{dp} = p\frac{dZ}{d\sigma}\frac{d\sigma}{dp} = -\frac{2i}{\beta_n}\left(\beta_n^2 + \frac{\alpha_m^2}{a^2}\right)(k^2l\beta_n^2 + lh^2 + kh),$$

which may be written

$$p\frac{dZ}{dp} = -\frac{i}{\beta_n^2}\left(\beta_n^2 + \frac{\alpha_m^2}{a^2}\right)(h^2 + k^2\beta_n^2)\,(2\beta_n l + \sin 2\beta_n l).$$

Similarly,

$$Y = \frac{2i}{\beta_n k}(h^2 + k^2\beta_n^2)\cos\beta_n l\cos\beta_n z.$$

In order to express the final solution more compactly, put

$$\left.\begin{aligned} A_m &= \left(k\frac{\alpha_m}{a} + h\right)e^{\frac{\alpha_m}{a}l}, \\ B_m &= \left(k\frac{\alpha_m}{a} - h\right)e^{-\frac{\alpha_m}{a}l}. \end{aligned}\right\} \qquad 10.5$$

The final result is

$$v = 2\epsilon b\sum_{m=1}^{\infty}\frac{J_0\left(\frac{\alpha_m}{a}r\right)}{(b^2\alpha_m^2+1)J_0(\alpha_m)}\left\{\frac{A_m e^{\frac{\alpha_m}{a}z} + B_m e^{-\frac{\alpha_m}{a}z}}{A_m^2 - B_m^2}\right.$$

$$\left. - \frac{2}{k}\sum_{n=1}^{\infty}\frac{\beta_n\cos\beta_n l\cos\beta_n z\exp.\left\{-\kappa\left(\beta_n^2+\frac{\alpha_m^2}{a^2}\right)t\right\}}{\left(\beta_n^2+\frac{\alpha_m^2}{a^2}\right)(2\beta_n l + \sin 2\beta_n l)}\right\}. \qquad 10.6$$

Since $v = 0$ initially, we must have the expansion, valid for $-l \leq z \leq +l$,

$$\frac{A_m e^{\frac{\alpha_m}{a}z} + B_m e^{-\frac{\alpha_m}{a}z}}{A_m^2 - B_m^2} = \frac{2}{k}\sum_{n=1}^{\infty}\frac{\beta_n\cos\beta_n l\cos\beta_n z}{\left(\beta_n^2+\frac{\alpha_m^2}{a^2}\right)(2\beta_n l + \sin 2\beta_n l)}. \qquad 10.7$$

As far as this expansion itself is concerned, α_m may be wholly arbitrary. This expansion may be verified by expanding the left-hand side, denoted $f(z)$, in a Fourier's series,

$$f(z) = \sum_{m=1}^{\infty} a_m\cos\beta_m z,$$

where the β_m are the roots of $\tan\beta l = h/k\beta$, and determining the coefficients, in the usual way.

11. As an example of the application of this method to three variables, consider the same cylinder as in the last problem, but let the radiation be incident on one half of the curved surface. Using cylindrical coördinates, the differential equation to be solved is

$$\frac{\partial^2 v}{\partial r^2} + \frac{1}{r}\frac{\partial v}{\partial r} + \frac{1}{r^2}\frac{\partial^2 v}{\partial\theta^2} + \frac{\partial^2 v}{\partial z^2} + q^2 v = 0,$$

with $p = -\kappa q^2$. Assuming a solution in the form $v = v_1 Z$, where

v_1 is a function of r and θ, and Z a function of z only, we get

$$\frac{\partial^2 Z}{\partial z^2} = \lambda^2 Z,$$

and assuming $v_1 = R\Theta$, where R, Θ are functions of r, θ, respectively,

$$\frac{\partial^2 \Theta}{\partial \theta^2} = -n^2\Theta,$$

$$\frac{\partial^2 R}{\partial r^2} + \frac{1}{r}\frac{\partial R}{\partial r} + \left(q^2 + \lambda^2 - \frac{n^2}{r^2}\right) R = 0.$$

Let

$$\sigma^2 = q^2 + \lambda^2.$$

Then the solutions of these three ordinary equations are

$$Z = Ae^{\lambda z} + Be^{-\lambda z},$$
$$\Theta = C\cos n\theta + D\sin n\theta,$$
$$R = J_n(\sigma r),$$

where n can have only integral values in order that v may be periodic in θ with the period 2π. Taking the origin of coördinates at the center of the cylinder, and observing that v must be the same at equal distances along the z-axis on each side of the origin, $A = B$, and

$$v = A(e^{\lambda z} + e^{-\lambda z})(C\cos n\theta + D\sin n\theta)J_n(\sigma r).$$

The boundary conditions are

$$\text{At } z = +l, \quad -k\frac{\partial v}{\partial r} = hv,$$

$$\text{At } z = -l, \quad k\frac{\partial v}{\partial r} = hv.$$

It follows that

$$k\lambda(e^{-\lambda l} - e^{\lambda l}) = h(e^{-\lambda l} + e^{\lambda l}).$$

Put

$$\lambda^2 = -\beta^2, \quad \lambda = i\beta,$$

Therefore these boundary conditions lead to

$$\tan \beta l = \frac{h}{k\beta}\cdot \qquad 11.1$$

This is the same equation as was found in the previous problem,

and its roots will be denoted by β_m. The symbolic solution, satisfying the conditions at $z = \pm l$, is therefore

$$v = \sum_{n=0}^{\infty} \sum_{m=1}^{\infty} 2A \cos \beta_m z (C_n \cos n\theta + D_n \sin n\theta) J_n(\sigma r).$$

At $r = a$ the boundary condition is

$$- k \frac{\partial v}{\partial r} = hv - \epsilon f(\theta),$$

where

$$\begin{aligned} f(\theta) &= \cos \theta \text{ for } - \pi/2 \leq \theta \leq + \pi/2 \\ &= \quad 0 \quad \text{for } + \pi/2 \leq \theta \leq + 3\pi/2. \end{aligned}$$

The Fourier expansion for $f(\theta)$ has already been obtained and is given by equations 9.1 and 9.2. In order to satisfy the boundary condition at $r = a$ for all values of z between $+ l$ and $- l$, we need to expand a constant in a Fourier's series of the form

$$1 = \sum_{m=1}^{\infty} b_m \cos \beta_m z,$$

where the β_m are the roots of 11.1. We can obtain this by the usual method, or we can get it immediately from 10.7 by taking $\alpha_m = 0$. Then $A_m - B_m = 2h$, and

$$1 = 4 \sum_{m=1}^{\infty} \frac{\cos \beta_m z \sin \beta_m l}{2\beta_m l + \sin 2\beta_m l}.$$

The condition at $r = a$ now leads to

$$\sum_{m=1}^{\infty} \sum_{n=0}^{\infty} 2A_m \cos \beta_m z (C_n \cos n\theta + D_n \sin n\theta)(k\sigma J_n'(\sigma a) + hJ_n(\sigma a))$$
$$= 4\epsilon \sum_{m=1}^{\infty} \sum_{n=0}^{\infty} \frac{c_n \cos n\theta \cos \beta_m z \sin \beta_m l}{2\beta_m l + \sin 2\beta_m l}.$$

The constants A_m are wholly arbitrary. We can therefore take

$$2A_m = \frac{\sin \beta_m l}{2\beta_m l + \sin 2\beta_m l}.$$

Comparing the coefficients of $\cos n\theta$ and $\sin n\theta$ on the two sides of this equation, we get

$$D_n = 0,$$

$$C_n = 4\epsilon \frac{c_n}{k\sigma J_n'(\sigma a) + hJ_n(\sigma a)}.$$

The symbolic solution of the problem therefore becomes

$$v = 4\epsilon \sum_{m=1}^{\infty} \sum_{n=0}^{\infty} \frac{c_n \sin \beta_m l \cos n\theta \cos \beta_m z J_n(\sigma r)}{(2\beta_m l + \sin 2\beta_m l)\{k\sigma J_n'(\sigma a) + hJ_n(\sigma a)\}}.$$

The part of this symbolic solution depending on p is

$$\frac{Y}{Z} = \frac{J_n(\sigma r)}{k\sigma J_n'(\sigma a) + hJ_n(\sigma a)}.$$

When $p = 0$, $q^2 = 0$, and $\sigma^2 = -\beta^2$. The Bessel functions with a purely imaginary argument are therefore required. These functions are given by

$$J_n(ix) = i^n I_n(x),$$
$$J_n'(ix) = i^{n-1} I_n'(x).$$

Therefore,

$$\frac{Y(0)}{Z(0)} = \frac{I_n(\beta_m r)}{k\beta_m I_n'(\beta_m a) + hI_n(\beta_m a)}.$$

Denoting the roots of the equation

$$Z = bxJ_n'(x) + J_n(x) = 0,$$

where $b = k/ha$, by $\alpha_{s,n}$, the permissible values of p are given by

$$p_s = -\kappa\left(\beta_m^2 + \frac{\alpha_{s,n}^2}{a^2}\right).$$

With these values of p_s,

$$p\frac{dZ}{dp} = -\frac{a}{2k\alpha_{s,n}^2}\left(\beta_m^2 + \frac{\alpha_{s,n}^2}{a^2}\right)(k^2\alpha_{s,n}^2 + h^2a^2 - k^2n^2)J_n(\alpha_{s,n}),$$

$$Y = J_n\left(\frac{\alpha_{sn}}{a} r\right)$$

and the final solution of the problem is

$$v = \frac{4\epsilon}{h} \sum_{m=1}^{\infty} \sum_{n=0}^{\infty} \frac{c_n \sin \beta_m l \cos \beta_m z \cos n\theta}{2\beta_m l + \sin 2\beta_m l} \left\{ \frac{I_n(\beta_m r)}{ab\beta_m I_n'(\beta_m a) + I_n(\beta_m a)} \right.$$
$$\left. - 2b \sum_{s=1}^{\infty} \frac{\alpha_{sn}^2 J_n\left(\frac{\alpha_{sn}}{a} r\right) \exp.\left\{ -\frac{\kappa}{a^2}(a\beta_m^2 + \alpha_{s,n}^2)t \right\}}{(a^2\beta_m^2 + \alpha_{s,n}^2)(b^2\alpha_{s,n}^2 + 1 - b^2n^2)J_n(\alpha_{s,n})} \right\}. \quad 11.2$$

It is easy to show that on putting $l = \infty$ this reduces to the solu-

tion of the analogous problem for the infinite cylinder. For when $l = \infty$, the only root of 11.1 is $\beta = 0$; for this value,

$$\frac{\sin \beta l}{2\beta l + \sin 2\beta l} = \frac{1}{4}.$$

The first term in the brackets becomes

$$\frac{1}{nb+1}\left(\frac{r}{a}\right)^n,$$

leading to equation 9.3.

12. Since $v = 0$ at $t = 0$, we have the expansion

$$\frac{I_n(\beta_m r)}{ba\beta_m I_n'(\beta_m a) + I_n(\beta_m a)}$$

$$= 2b\sum_{s=1}^{\infty}\frac{\alpha_{s,n}^2 J_n\left(\dfrac{\alpha_{s,n}}{a}r\right)}{(a^2\beta_m^2 + \alpha_{s,n}^2)(b^2\alpha_{s,n}^2 + 1 - b^2n^2)J_n(\alpha_{s,n})}.$$

In this expansion, considered by itself, β_m may have any positive value. Taking $\beta_m a = 1$, and $r/a = x$, we get the expansion

$$\frac{I_n(x)}{bI_n'(1) + I_n(1)}$$

$$= 2b\sum_{s=1}^{\infty}\frac{\alpha_{s,n}^2 J_n(\alpha_{s,n}x)}{(1 + \alpha_{s,n}^2)(b^2\alpha_{s,n}^2 + 1 - b^2n^2)J_n(\alpha_{s,n})}, \qquad 12.1$$

valid for all positive values of b, and for $0 \leq x \leq 1$.

If we attempt to expand $I_n(x)$ in a Dini series, we have

$$I_n(x) = \sum_{s=1}^{\infty} b_s J_n(\alpha_{s,n}x).$$

Now (Watson, l.c., p. 597),

$$b_s = \frac{2\alpha_{s,n}^2 \int_0^1 tI_n(t)J_n(\alpha_{s,n}t)dt}{(\alpha_{s,n}^2 - n^2)J_n^2(\alpha_{s,n}) + \alpha_{s,n}^2 J_n'^2(\alpha_{s,n})},$$

where $\alpha_{s,n}$ are the roots of

$$b \cdot xJ_n'(x) + J_n(x) = 0$$

or

$$J_n'(\alpha_{s,n}) = -\frac{J_n(\alpha_{s,n})}{b\alpha_{s,n}}.$$

It therefore follows that

$$b_s = \frac{2\alpha_{s,\,n}^2 \int_0^1 tI_n(t)J_n(\alpha_{s,\,n}t)dt}{(\alpha_{s,\,n}^2 - n^2 + (1/b^2))J_n^2(\alpha_{s,\,n})},$$

and comparing with the expansion 12.1 we get the definite integral

$$\int_0^1 tI_n(t)J_n(\alpha_{s,\,n}t)dt = \frac{\{bI_n'(1) + I_n(1)\}J_n(\alpha_{s,\,n})}{b(1 + \alpha_{s,\,n}^2)}. \qquad 12.2$$

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THE "INDIAN SUMMER" AS A CHARACTERISTIC WEATHER TYPE OF THE EASTERN UNITED STATES.

By ROBERT De C. WARD.

(Read April 20, 1923.)

Description of Indian Summer.—No type of American weather has been accorded such widespread and unstinted praise as has our "Indian summer." Poets, masters of literature, historians, travelers, meteorologists, and even the daily newspapers have united in their enthusiastic descriptions of its charms. The task is not an easy one to choose from among these many printed accounts the two or three which will best serve to introduce the subject of this paper. It may perhaps not be inappropriate to single out two as having been written by men who are among the most widely known American writers of the past generation. In his "History of the Conspiracy of Pontiac," Francis Parkman wrote thus:

> . . . then succeeded that gentler season which bears among us the name of the Indian summer; when a light haze rests upon the moving landscape, and the many-colored woods seem wrapped in the thin drapery of a veil; when the air is mild and calm as that of early June, and at evening the sun goes down amid a warm, voluptuous beauty, that may well outrival the softest tints of Italy. But through all the still and breathless afternoon, the leaves have fallen fast in the woods, like flakes of snow, and everything betokens that the last melancholy change is at hand.[1]

With his inimitable charm, Dr. Oliver Wendell Holmes described the Indian summer of his beloved New England in the following delightful passage:

> In October, or early in November, after the "equinoctial" storms, comes the Indian summer. It is the time to be in the woods or on the seashore—a sweet season that should be given to lonely walks, to stumbling about in old churchyards, plucking on the way the aromatic silvery herb everlasting, and smelling at its dry flower until it etherizes the soul into aimless reveries outside of space and time. There is little need of trying to paint the still, warm, misty, dreamy

[1] Francis Parkman, "History of the Conspiracy of Pontiac," 1851, p. 404.

Indian summer in words; there are many states that have no articulate vocabulary and are only to be reproduced in music, and the mood this season produces is of that nature. By and by, when the white man is thoroughly Indianized (if he can bear the process), some native Haydn will perhaps turn the Indian summer into the loveliest *andante* of the new "Creation."[2]

These quotations indicate, in far more poetic and expressive terms than those which the present writer has at his command, the characteristics of the Indian summer: the calm, sunny days; the dry, mild and genial atmosphere; the smoky haze which lends to the distant view a soft, indistinct, impressionistic tone and paints the sunset a glorious but subdued red; the wonderful coloring of the autumnal foliage; the welcome return, for a short space, of summer warmth following the first frosty nights and cool days of advancing winter.

Origin of the Name "Indian Summer."—Much interest centers in the origin and meaning of the term Indian summer, and diligent search has been made by scholars of the literature bearing upon this question. Among these, Mr. Albert Matthews, of Boston, has made the most exhaustive study of the historical usage of the name, as well as a critical examination of the various explanations which have been given of its original meaning.[3]

The first use of the name was, for some twenty years, attributed by Matthews to Major Ebenezer Denny, who mentioned it in his "Journal" kept at Le Boeuf, near the present city of Erie, Pa., October 13, 1794. An earlier case has, however, since been reported by Matthews. This appears in a letter dated "German-flats, 17 Janvier, 1778." In this, Crèvecoeur gives a "Description d'une Chute de Neige, dans le Pays de Mohawks, sous le rapport qui interesse le Cultivateur Américain."[4]

Speaking of heavy autumn rains, followed by severe frost, the writer says:

[2] Oliver Wendell Holmes, "Pages from an Old Volume of Life," 8vo, Boston, Houghton, Mifflin and Co., 1891, pp. 165–166.

[3] Albert Matthews, "The Term Indian Summer," *Month. Wea. Rev.*, Vol. 30, 1902, pp. 19–28, 69–79. This paper contains a very complete bibliography and many quotations from the original sources. See also Josiah Morrow, "Indian Summer," ibid., Vol. 39, 1911, pp. 469–470.

[4] "Lettres d'un Cultivateur Américain . . . depuis l'Année 1770 jusqu'en 1786, par M. St. John de Crèvecoeur, Traduites de l'Anglais," Paris, 1787, I., p. 294.

Sometimes the rain is followed by an interval of calm and warmth which is called the Indian summer (l'Eté Sauvage); its characteristics are a tranquil atmosphere and general smokiness. Up to this epoch the approaches of winter are doubtful; it arrives about the middle of November, although snows and brief freezes often occur long before that date.[5]

Various suggestions have been made to explain the use of the word *Indian* in connection with Indian summer. One is that the Indians selected this time of the year as their hunting season, "to which it is highly conducive," as an unknown writer remarked, "not only on account of the plenty and perfection of the game, but also in consequence of the haziness or obscurity of the air, which favors a near, and unsuspected approach, to the object of pursuit."[6] Another suggestion is that the characteristic smoky haze in the air at this season was due to the fact that the Indians then set fire to the prairie grass, woods, and underbrush. With reference to these views, Matthews observes that the Indians also hunted and set fires at other times of the year. Other explanations are that the Indians made use of the dry, clear weather for attacking the whites again before winter set in; that this was the season for the Indian harvest; that the term was derived from the prevalence of southwesterly winds regarded by the Indians as sent by special favor from a beneficent deity thought to reside in the southwest, and that the unreliability of Indian summer weather suggested the deceitfulness of the Indians. After a critical examination of these different theories, Matthews concludes "we shall therefore be obliged to suspend judgment with respect to the origin of the name of the Indian summer season until fresh evidence as to the early history of the term is produced. . . . It is possible that the name will some day be traced to an Indian myth or legend."[7]

Professor George Lyman Kittredge, of Harvard University, is another scholar who has investigated the origin of the term.[8] Pro-

[5] Translation by Dr. Cleveland Abbe, Jr. See note by Albert Matthews in *Month. Wea. Rev.*, Vol. 39, 1911, p. 469.

[6] "Essay on the Indian Summer, read at a meeting of the Maryland Academy of Sciences by One of its Members, Baltimore, December 16, 1833." *Amer. Journ. Sci.*, Vol. 27, 1835, pp. 140–147.

[7] Loc. cit., footnote 3.

[8] George Lyman Kittredge, "The Old Farmer and His Almanack," 8vo, Cambridge, Mass., Harvard University Press, 1920, pp. 191–207.

fessor Kittredge thinks it far-fetched to attribute the haziness of the sky to the brush and forest fires kindled by the Indians in the autumn, and believes it "far more reasonable" to think that reference was made to the "proverbial deceitfulness and treachery of the natives" or to their "equally proverbial instability." He also thinks it "conceivable that Indian summer was at first equivalent (among the earliest English immigrants) to 'fools' summer.' If so, we seem to have a parallel to the 'Old Women's Summer' of the Germans. . . ."[9] The conclusion, however, is that the "origin of the term is a mystery" (p. 193).

A wholly different origin of the "Indian summer" has been suggested by Mr. Horace E. Ware, who indicates that Indian in this connection may have referred to a nautical use in the British Indian seas.[10] Under the Regulations of the British Board of Trade one of the load-lines on ships bears the initial letters "I. S.," this indicating the maximum depth to which vessels can be loaded for voyages during the "Indian summer," which means the fine weather season in the Indian seas. It is possible, though unlikely, that the Indian summer of the eastern United States was thus named by travelers or seamen who saw in it some resemblance to the fine weather during the northeast monsoon of India.

Whatever may have been its origin, the term Indian summer was evidently first used in the eastern United States, probably in New England, and spread thence westward across the Mississippi valley; southward along the Atlantic coast, and northward into Canada. It appears, however, today to be most familiarly known and most commonly employed in the northeastern portion of the United States.

When Does Indian Summer Come?—Opinions have differed a

[9] The term *Altweibersommer* is applied to similar spells of autumn weather in Germany.

[10] Horace E. Ware, "Notes on the Term 'Indian Summer,'" *Publ. Colonial Soc. Mass.*, Boston, Mass., Vol. 18, 1917, pp. 123–130. The author cites a poem by Philip Freneau, dated 1815, as the first appearance of the name in poetry, and quotes Mrs. Sigourney's poem on the same subject, written before but published in 1849. See also C. F. Talman, "Indian Summer," *Month. Wea. Rev.*, Vol. 43, 1915, pp. 44–45. William G. Reed, "Indian Summer and Plimsoll's Mark," ibid., Vol. 44, 1916, p. 575. The latter paper gives a photograph (Fig. 2, opposite p. 575) of the load-line marks on the bow of the British S. S. *Dramatist*, of Liverpool, taken at San Pedro, Cal., October 14, 1916.

good deal both as to the time of occurrence and also as to the duration of Indian summer. This fact becomes obvious to anyone who examines the literature on this subject, or who questions persons with whom he comes in contact. The term has been most commonly used for warm, dry, hazy spells in the autumn months, but it has also been applied to warm spells in December and even in January. Some writers have referred to it as peculiar to New England, while others have stated that it occurs widely over most of the United States, even on the Pacific coast. Others, among the older writers, held the view that the Indian summer was more marked in their time than formerly, while another group maintained that it was less marked. One unknown author, who held that "the Indian summer appears usually in the month of November," went so far as to observe that a similar type of weather "is by no means uncommon in the month of October, and is frequently mistaken for the true Indian summer by persons unacquainted with the proper period of its accession." Blodget, on the other hand, whose "Climatology of the United States" was one of the milestones in the history of American climatology, maintained that it is held certain that one such period, of some days' duration, will occur in October of every year.[11] In spite of these divergent views, it is today distinctly the trend of popular opinion that Indian summer comes in the autumn, some time in October or November, after the first severe frost; and that its length is indefinite, varying in different years.[12] Sometimes, however, there is no Indian summer at all, while in other years two or three spells of warm weather all seem to merit the name. During the past twenty-odd years, at frequent intervals during the autumn months, the writer has questioned his students regarding their own impressions on this subject and finds that their views are the same as the majority opinion above stated. In some years, when more than one spell of Indian summer weather occurred, there has been considerable doubt as to which one of these was *the* Indian summer, the preference being to apply that term to the longest and most marked of these spells.

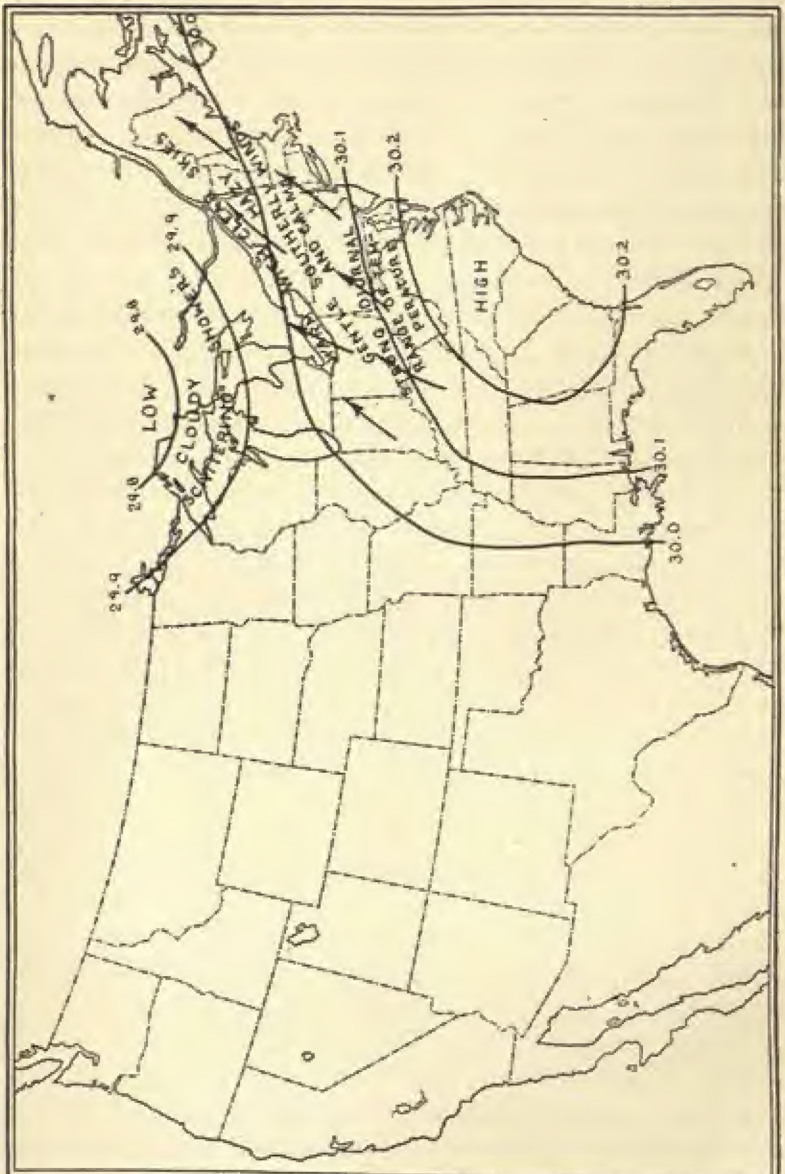
[11] Lorin Blodget, "Climatology of the United States," large 8vo, Philadelphia, Pa., 1857, p. 233.

[12] See, *e.g.*, Cleveland Abbe, "The Time and Duration of the Indian Summer at Washington," *Month Wea. Rev.*, Vol. 33, 1905, p. 489.

A collection of daily weather maps for autumn days of marked Indian summer characteristics has been made during a number of years past. On the basis of these maps, a very much generalized sketch map was drawn, free-hand, showing in broad outline the general distribution of pressure, winds, and weather prevailing during these Indian summer periods. This map is not a composite, traced off from a large number of maps and then generalized, nor does it represent any individual map.

The conditions here shown are typical of most Indian summer weather maps over the eastern United States. A dominant anticyclone is central over the southern Atlantic coast. A moderate depression is over the Lakes. Generally clear weather prevails, with some cloudiness and perhaps scattered local showers over the Upper Lake region. There are gentle southerly to southwesterly winds or calms, hazy skies and temperatures above the seasonal average, with fairly well-marked diurnal ranges, giving cool, pleasantly refreshing nights. Many modifications of the type here shown may occur. Thus the high pressure area may be somewhat farther north or west; or the low may be better defined, and over the northern Plains. In the latter case, conditions favorable to warm, fair weather prevail west of the Mississippi valley. Again, the depression may be farther northeast, towards the Gulf of St. Lawrence. These variations in pressure distribution bring about changes in the area covered by and in the local characteristics of the Indian summer type, but as long as the general situation here outlined continues, the same general weather conditions will last. It is quite characteristic of Indian summer spells that they usually persist for several days, the depressions being poorly defined and moving slowly eastward, while the anticyclone maintains its position without much change. Such a spell of weather usually breaks up with a general, often a cold, rain, accompanying a well-marked cyclonic storm.

Indian Summer Weather Type Maps Occur at All Seasons.—The popular impression regarding Indian summer, that it comes after a severe frost in autumn, is associated with the idea that the special type of weather map which gives rise to this well-known spell occurs only in the autumn. This is not the case. Such general pres-



Indian Summer Type Map.

sure conditions as those broadly generalized in the accompanying map may occur in any month, although the weather which accompanies them and the intensity and movements of the controlling high and low pressure areas vary with the seasons. For a good many years the writer has collected Indian summer type weather maps whenever such were found. The charts cover every month in the year. In other words, spells of fine weather, with temperatures above the average, hazy skies and gentle southerly winds are likely to come at any time. In winter, when there is snow on the ground, such a condition brings a thaw. The warm damp winds, chilled as they blow over the cold surface, may even become foggy or cloudy. If the ground is bare, the sky is clear or fair, and we have a spell of "spring-like" weather. An Indian summer type about December 25 gives a "green Christmas"; in January, a "January thaw"; in March, April and May, a spring "hot day"; in summer, a hot wave.

The Special Peculiarities of the Indian Summer Type in the Autumn Months.—Is there, then, any special peculiarity about this type of weather when it occurs in autumn, and is generally termed the true Indian summer? The answer to this question is probably to be found in the interaction of a number of factors. In the fall of the year there is characteristically something in the nature of a stagnation, or slackening, in the general movements of the atmosphere. The anticyclone over the South Atlantic slope often persists for several days, while the usual procession of cyclonic depressions passing over the Lakes and down the St. Lawrence Valley is interrupted, and weak, slow-moving and often poorly developed low pressure areas appear instead. The barometric gradients are apt to be weak. Autumn is a transition season. The cyclonic activity of the colder months has not yet set in. The thunderstorm activity of the summer has passed. There is a pause, as it were, before the turbulence of the winter begins in earnest, and a period, or several periods, of warm, quiet weather may set in. As an early writer poetically expressed it, "the air is perfectly quiescent and all is stillness, as if Nature, after her exertions during the summer, were now at rest." [13] Over much of the country, especially in the east and southeast, the

[13] John Bradbury (1817), quoted by Albert Matthews, loc. cit., footnote 3, p. 24.

autumn months are a season of minimum, or at least of a small rainfall. Thus dry spells are likely to be especially frequent then. This is, furthermore, the time when forest, brush, and grass fires are common, accidentally started by a careless hunter or tramper, or by the sparks from a locomotive. It is also a time when dead leaves and other garden rubbish are apt to be burned, in the final clearing up of many gardens at the close of the summer. Thus the more or less calm and stagnant atmosphere often becomes smoky. It is this smoke, combined with the haze caused by the condensation of water vapor in the warm southerly air currents, and with the dust derived from the minute particles of the dry leaves, which gives the softness and impressionistic quality to the distant view, and adds so much to the beauty of the typical American Indian summer. In addition, the long nights and the small vertical temperature gradient of autumn contribute to the accumulation of smoke and to the production of quiet conditions at that time of year. And, finally, there is the satisfaction which comes from experiencing days of real warmth after the first chill of autumn frosts—a reminder of the summer which has passed; a final breathing spell when we may once more revel in the full enjoyment of Outdoors before the storms and cold of winter change the aspect of Nature.[14]

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[14] For additional references see: Lyman Foot, "Remarks on Indian Summers," *Amer. Journ. Sci.*, Vol. 30, 1836, pp. 8–15; "On the Cause of the Peculiar Aspect of the Air in the Indian Summer," ibid., 2d Ser., Vol. 18, 1839, pp. 66–67; Joseph E. Willet, "Indian Summer," ibid., Vol. 44, 1867, pp. 340–347; W. M. Wilson, "Indian Summer," *Month. Wea. Rev.*, Vol. 30, 1902, pp. 440–442; Robert M. Brown, "Indian Summer," *Journ. Geogr.*, Vol. 8, 1909, pp. 25–31.

PREHISTORIC MISNOMERS.

By EDWIN SWIFT BALCH.

(*Read April 19, 1923.*)

During the past hundred years the study of prehistoric man has become of continually increasing scientific importance. At first, everything connected with it, in more ways than one, was unbroken ground. This necessitated an entirely original terminology which grew gradually and is still growing. Some of this is descriptive and appropriate, but, probably partly owing to the imperfect knowledge of the early students of the subject, some of it is non-descriptive and confusing. And in an attempt to make clear why certain terms used in connection with prehistoric man are misleading, it is necessary to say a few words about certain fundamentals of the subject.

There are four classes of stone artifacts or stone implements, terms applying equally to stones used as tools or to stones used as weapons, and unquestionably these stone artifacts evolved in the following order: (1) natural stones or pebbles unworked by man; (2) stones or pebbles fractured by man into indeterminate accidental shapes; (3) stones or pebbles fractured and fashioned by man into definite artificial forms; (4) stones or pebbles fractured and fashioned by man into definite artificial forms and then polished.

Polished-stone implements, those belonging to the fourth class, were the first accepted by the pioneers in prehistoric archeology as the handiwork of man, and with their recognition came the certitude of the existence of a Stone Age. Then chipped-stone implements with artificial shapes, those belonging to the third class, were recognized. Next the pioneers became aware of the fact that polished-stone implements were found only in later archeological horizons, while chipped-stone implements were found in early ones as well as in later ones. Reasoning from this and from imperfect local data, archeologists soon began to speak of the New Stone Age and the Old Stone Age. Translations of these titles into Greek were then made for scientific use and the supposed periods became known as the Neo-

lithic Age and the Paleolithic Age, and the implements as neoliths and paleoliths. In the course of time, also, certain archeologists realized that before man thought of fracturing stones into definite shapes, he must have fractured stones merely to obtain a cutting edge or a point. And to such stones, those of class 2, of which millions must have been made, even if they can not be positively identified as the handiwork of man, some bright individual affixed the name of dawn stones or eoliths. For class 1, no defining name has been coined, but the terms pre-eolithic and pre-eoliths are sometimes made use of and fairly cover the situation.

The weak spot in this nomenclature, however, is that the terms eolith, paleolith, and neolith refer to time and not to kind. They do not describe the different kinds of stone implements, they merely imply that certain kinds are older than certain other kinds, and as this is only partly true, it creates confusion. Stone implements undoubtedly evolved in the order of the four classes mentioned, but they evolved thus at different times in different places. For instance, there is a growing certainty that neoliths were in general use in west central Asia many millenniums before they either evolved or were introduced into Europe. That is to say, the Neolithic epoch in west central Asia was contemporaneous with the latter part of the Paleolithic epoch in Europe.

But of still greater importance is the fact that all four classes of stone implements have survived to our own generation. Boys who throw stones at birds and men who throw stones at one another are using the earliest missile known to man. When workmen break up stones into indefinite shapes to strew on roads and our tires explode from contact with their cutting edges or their sharp points, we are unpleasantly reminded that eoliths are still in use. One tribe of primitive men at least, the Tasmanians, was in a pure Paleolithic epoch when the oldest living members of the American Philosophical Society were boys. And as far as can be gathered from the very uncertain reports, some of the American Indians inhabiting the virgin forests round the headwaters of the Amazon have not advanced beyond polished stone implements—that is, they are still in a Neolithic age.

The terms eoliths, paleoliths, and neoliths, and their derivatives,

Eolithic period, Paleolithic period, and Neolithic period, however, though founded on imperfect knowledge and not descriptive, nevertheless have become consecrated by usage. And therefore they will continue to be employed. But it should be understood that they apply to the order of evolution of stone implements and not to the actual time of manufacture of any particular implement. In other words, archeologists should recognize that these terms are restricted in meaning and that in certain respects they are incorrect.

To this somewhat erroneous albeit usable terminology, however, some archeologists are now beginning to add one thoroughly erroneous title, namely, Mesolithic period or Middle Stone Age. The logical sequence of this would be the term mesolith, but this is so exceedingly inappropriate that, as far as I know, no one as yet has attempted to use it. Another title which is right enough if used correctly, but which lately is beginning to be used incorrectly, is Prepaleolithic. And it is time to put up a warning signal against these confusing innovations.

What, now, is the title Mesolithic period supposed to cover? Not very long after archeologists began digging scientifically in Europe, they became aware that formed chipped-stone implements are found evolving from very rough ones to highly finished ones in a series of superimposed horizons which became known as the Chelléen, Acheuléen, Moustérien, Aurignacien, Solutréen, and Magdalénéen horizons. Then came a gap in the European strata, and then above the gap came polished stone implements. This gap for some years was usually spoken of as the hiatus. But in course of time, by unremitting digging, this hiatus became bridged by the discovery of several horizons of which the most important are the Azilien and the Campignien. And this former hiatus it is which some archeologists, assuming that the Paleolithic period stops at its lower edge, are beginning to call the Mesolithic period.

But any archeologist who accepts the term Mesolithic or Middle Stone period, perforce must accept the term mesolith or middle stone. Now, what would mesolith mean? If it means anything at all, it must mean a stone implement which is neither a formed chipped-stone implement nor a formed polished-stone implement. But while it is true that the artifacts of the Azilien and Campignien horizons

are not polished-stone implements, it is equally true that they are formed chipped-stone implements. They are a direct advance by evolution from earlier forms of chipped-stone implements. And the forms of two of the Campignien implements are of especial interest, because they are the prototypes of our present-day hatchet or axe and of our pick or hoe, and they show when the change from the life of the hunter into the life of the agriculturist began in Europe. But since these Campignien implements are formed chipped-stone implements they are paleoliths and they belong to the Paleolithic period. And this being the case, the term Mesolithic period is a misnomer and the sooner it is abandoned the better for prehistoric archeology.

Turning now to the term Pre-paleolithic, what does it mean? It can mean with accuracy only one thing, and that is the times when man was already on the earth and was using only either unworked pebbles or stones fractured into indeterminate forms. But for these times we have already the terms Pre-eolithic period and Eolithic period, which are more definite than Pre-paleolithic, regardless of whether any particular shapeless pieces of flint can be verified as having been fractured by the forces of nature or by the hand of man.

There are signs, however, that the term Pre-paleolithic may become employed inaccurately. And this seems to be due to certain archeologists still apparently considering the terms Paleolithic period and Neolithic period as beginning and ending at definitely fixed archeological periods of time. But they do not. The Neolithic begins with the first polished-stone implements and the date when these were made is slowly retrogressing. The Paleolithic begins with the first formed chipped-stone implements and the date when these were made is also slowly retrogressing. During the last half of the nineteenth century it was generally accepted that paleoliths were first manufactured in the early Pleistocene, some time before the important Chellēen horizon. But within the last few years a chipped-stone implement bearing horizon which is very close to, if not actually in, Pleiocene strata has been traced at Cromer, England. Another which appears without a shadow of doubt to be Pleiocene has been discovered at Foxhall, near Ipswich, England. And judging only from the illustrations published of the implements taken from this Foxhallian horizon, there can be no doubt that they are formed

chipped-stone implements—that is, paleoliths. And what they do is to throw back immensely the time at which the making of paleoliths began in the Old World.

In one direction, a great improvement in prehistoric terminology has recently come to the fore, and that relates to the advances and retreats of the northern ice. At first only one advance was recognized, then two, and now the number of the advances is figured out by some geologists as three, by some as four, by others as five, by still others as six. There is a beautiful uncertainty in the matter. For these several advances and retreats, various sets of names have been invented, some for Europe, others for America. It is hard to memorize the order of these names and still harder to know which names of one set coincide with the names of another set. Fortunately, however, this cumbrous nomenclature is gradually being abandoned and the glacial advances and retreats are becoming known as the First Glacial period, First Interglacial period, Second Glacial period, Second Interglacial period, etc. And as the advances and retreats were unquestionably simultaneous in the Old World and in the New World, these terms apply equally to both and eliminate further confusion.

There is a tendency, however, among the prehistoric archeologists of today to settle on the Moustérien horizon of the European Paleolithic as coinciding with the last Glacial period, and to place the Aurignacien, Solutréen, Magdalénéen, Azilien, Campignien, and later horizons, in the Post-Glacial. But this latter classification seems both incorrect and confusing. There is indeed now, it is true, no doubt that the Moustérien horizon coincided partly, perhaps wholly, with a Glacial period. But there is also no doubt that in the succeeding Aurignacien the climate became much warmer. Following this, in the Solutréen the climate began to grow colder again, and in the succeeding Magdalénéen it became and long remained very cold. So cold was it, in fact, that the hairy mammoth, the wooly rhinoceros and the reindeer throve plentifully in south-central Europe, as is proved by their numerous remains and by the splendid drawings of them which the ancestors of Paul Potter, Barye and Chanler, left for us on the walls of caverns and on pieces of stone or bone or ivory.

It was, indeed, from these portraits of the Magdalénéen heavily furred great mammals more than from anything else that the cave explorers of the middle of the nineteenth century first became aware that prehistoric man had lived in Europe during a glacial period. One has only to look into Boyd Dawkins's classic "Cave Hunting" to verify this statement, or to remember that certain distinguished French archeologists, such as Edouard Piette, spoke of the Magdalénéen as "l'âge du renne." Of course, a glacial period by any other name would be as cold, but since the Magdalénéen was glacial in its climate and in its fauna, why not call it glacial? Possibly it should be looked on as a separate glacial period: possibly as the latter half of the same glacial period as the Moustérien. But it certainly seems an error to place it in the Post-Glacial, which should properly begin with the Azilien, when the climate had grown much milder and the fauna was about the same as the fauna of the present day.

To sum up briefly the preceding remarks, if the term Mesolithic period were to become attached to the Azilien and Campignien horizons, then the term mesolith would perforce follow for their stone implements. But these are true paleoliths. Why not, therefore, continue to accept them as such and to recognize that the Azilien and Campignien belong to the Paleolithic? Likewise, as the implements of the Pleiocene Foxhallian horizon are formed chipped stones, why not call the Foxhallian horizon paleolithic, instead of speaking of it as Pre-paleolithic. And, lastly, since the Magdalénéen was very cold, why not accept it as a glacial period, or at least a part of a glacial period, instead of placing it misleadingly in the Post-Glacial?

THE RATE OF MOVEMENT IN VERTICAL EARTH ADJUSTMENTS CONNECTED WITH THE GROWTH OF MOUNTAINS.

By WILLIAM HERBERT HOBBS.

(*Read April 20, 1923*)

Until the advent of evolution in science, and its coming in the field of geology antedated that in the biological sciences by some decades, geological change was supposed to be concentrated within sudden cataclysms or revolutions which were believed to have punctuated the history of the world. These cataclysms were thought to have transformed the entire surface of the earth and made an end of all existing life, after which by a fiat of the Creator new life was started of a character notably different from that which had proceeded. Such a notion grew out of the Mosaic account of creation contained in the first chapter of the Pentateuch, and the idea of past geological time was the inherited one of the period which separated a time when the earth was " without form and void " from the present. The creation of the world was considered to be included within a period of seven days of twenty-four hours each, and Archbishop Usscher gave out officially that the period from the beginning of the world to that of the Christian era was 4,004 years. When geologists had become in a measure independent of Church authority, they, of course, interpreted the days of creation as periods rather than days, but they still held to the sharp separation between these periods—the cataclysms of the school of Cuvier. No such cataclysms having come within the experience of men, the geological past was of necessity assumed to have been different from the present. The Noachian Deluge, by which God destroyed the world, supplied, however, the type illustration, and was naturally looked upon as the latest of the great cataclysms. No doubt the notion concerning past miracles gave much inertia to the idea that times have changed and that very little concerning the past could be learned from a study of present conditions upon our planet.

Modern geology was ushered in by two founders of science, James Hutton and Charles Lyell, the former having given us the basal idea of evolution in inanimate Nature, with Lyell the masterful expositor of the doctrine. Thus Hutton is the Darwin and Lyell the Huxley of the geological doctrine of evolution which has become known as uniformitarianism. These men saw clearly that if limits were not placed upon the lapse of time, past changes could be assumed to have come about by the action of processes still in operation. Hutton declared, "I can see no vestige of a beginning, no prospect of an end," and Lyell preached, "The present is the key to the past." Unconsciously Lyell meant that the present in a country like Great Britain is the key to the past, and we know today that, geologically speaking, the British Isles represent a notably stable portion of the earth's surface where changes of the lithosphere surface proceed with exceptional slowness.

The immediate effect of the new doctrine of uniformitarianism was to dispel much illusion and to start observation of geological processes, with beneficial results which it would be difficult to overestimate. It would, however, be unfortunate if we were to overlook the fact that the acceptance of the doctrine resulted in drafts upon the bank of time upon which there was set no limit whatever. Estimates of the age of the earth since the beginning of life upon it soon went up into the hundreds of millions of years; and although a momentary check came in the attempts of physicists, and notably Kelvin, to limit these claims, the arguments from the physical field were subsequently shown to be subject to large error, with the effect of leading the geologists to carry their estimates still higher. The discovery of radio-activity caused the physicists to shift their ground and as a class to outrun the geologists in the extravagance of their claims, so that they estimated the age of the earth not in hundreds of millions, but in billions of years. One well-known geologist had, however, fixed the earth's age to be in the trillions of years.

The history of science shows that it has its fashions quite as inexorable as those of the social world, and it would be idle to deny that the fashion of the day among geologists is to claim ever greater time limits for the age of the earth. The American Philosophical Society has supplied proof of this by its recent symposium on the

measure of geological time.[1] It has, moreover, become the habit of some paleontologists, I much regret to say, to place opposite the divisions of the geological column a time scale aggregating some hundreds of millions of years and unfortunately giving to the reader the notion that these periods of time are well determined. I venture the prediction that such time scales will eventually be found to have the same degree of reliability as that of Archbishop Usscher which was long printed in the margins of our editions of the Bible. I here make no attempt to state any estimate concerning the age of the earth, my position being that of the agnostic in this matter. One may, however, assert with much positiveness that we have as yet no data of sufficient reliability concerning the age in years of our earth, and all those which attempt to give proportionate figures for the different ages have become involved with many unknown factors, some unconsciously introduced, which destroy their value. If the argument from the helium and lead ratios in radio-active minerals seems to offer an exception, it may be pointed out that the disproportionately small yardstick used for the distance to be measured is of a kind which has had many sad illustrations in the history of doctrines once accepted in science, but later abandoned. The use of the geothermic gradient to measure the temperature at the earth's center is one example only among many of the use of inadequate yardsticks, as well as of lack of knowledge concerning conditions within the space to be measured. My argument concerning the earth's age is admittedly destructive, but I have none the less something positive to contribute to the discussion.

All attempts of geologists to measure past time since the beginning of life upon the globe, and it is this period alone which I shall discuss, have been based upon the Lyellian doctrine of uniformitarianism—that the present is a reliable key to the past—and all geological methods of guaging this period have in the last analysis depended upon the rate of mass movement within the outer shell of the lithosphere—upon diastrophism. Rates of erosion and sedimentation are all dependent upon climatic conditions which affect the rate of weathering and upon movements of elevation and subsidence, to which erosion, transportation, and sedimentation are all adjusted.

[1] *Proc. Am. Phil. Soc.*, Vol. 61, 1922, pp. 247–288.

The salinity of the ocean, on which so many estimates of past time have been based, is also dependent upon much the same conditions.

In the latest noteworthy contribution to the subject of the earth's age, that of the late Professor Barrell,[2] the attempt is made to show that the stupendous estimates of past time which have been based upon the helium and lead ratios of radio-active minerals are reliable, and that by taking account of rhythms observable in the process of sedimentation and of other factors, the estimates of geological time by strictly geological methods may be properly stretched until they accord with those obtained from the study of radio-active minerals.

It will be readily admitted that recent study of the sedimentary strata has revealed many hitherto unsuspected diastrophic movements of relatively small measure which have yielded disconformities that less careful scrutiny had overlooked; and, other things being equal, such movements must add to the length of the record. On the other hand, a recognition of the fact that strata may be folded at the very surface of the earth, and not alone when buried to a depth of some fifteen or more miles beneath it, must reduce to a mere fraction the estimates of geological time based upon the assumption that every angular unconformity must involve diastropic changes of level measured in miles. (See the author's *Earth Evolution,* Chapter V.)

The time has arrived to state frankly that the fundamental basis of all estimates of geological time, the doctrine of uniformitarianism, is unsound. We know today that the earth instead of being in its normal condition—that which it has maintained throughout the greater part of its history—is passing out of one of the exceptional brief periods of glaciation, and that as a consequence its climate is quite abnormal. Yet upon climate the breakdown of the rocks in preparation for erosion and deposition is dependent. Today strongly marked climatic zones separated in a broad way by the parallels of latitude impose a barrier to the extended migration of delicate organic forms in the meridial direction, though during the greater part of geological history this climatic barrier was largely non-existent and plants had in consequence a relatively wide distribution over the earth's surface. What the rates of weathering, erosion, and sedimentation have been

[2] Joseph Barrell, "Rhythms and the Measurements of Geologic Time," *Bull. Geol. Soc. Am., Vol.* 28, pp. 745–904, pls. 43–46, 1917.

in an earth largely devoid of climatic zones is a matter of speculation. That they would all be widely different from what they are today is, however, quite certain. This matter is so vitally important to our subject that the authorities should be cited. In a paper read before the Geological Society of Washington in 1910, White and Knowlton [3] stated their conclusions in a particularly clear manner. Their conclusions were:

1. Relative uniformity, mildness (probably subtropical in degree), and comparative equability of climate, accompanied by a high humidity, have prevailed over the greater part of the earth, extending to, or into, the polar circles, during the greater part of geologic time since, at latest, the Middle Paleozoic. This is the regular, the ordinary, the normal condition. From a broad point of view these conditions are relatively stable.

2. The development of strongly marked climatic zones, at least between the polar circles, is exceptional and abnormal. It is usually confined to short intervals, or to intermittently oscillating short intervals, all within relatively short periods.

3. The periods of abnormal climatic differentiation are characterized by the development of extremes—*i.e.*, by extreme and abnormal heat or cold (glaciation), humidity, or aridity—which are local or regional in their occurrence and variable or unstable.

4. The brief geological period in which we live is a part of one of the most strongly developed and unstable of these abnormal intervals of radical change. The assumption that climatic variations, contrasting extremes, and complexity of combination and geographic distribution of climatic factors, such as now exist, are normal or essential, and that they were present also, though in slightly less degree, in all geological periods appears to be without paleobotanical warrant. The proposition that we are still in the glacial epoch is paleontologically true. We have no evidence that in any other post-Silurian period, with perhaps the exception of the Permo-Carboniferous glacial period, have the climatic distribution and segregation of life been so highly differentiated and complicated as in post-Tertiary time.

6. The development and existence of torridity—*i.e.*, of a torrid zone in the equatorial belt or any other great region of the earth—is concomitant and causally connected with the development of regional frost. It would appear that the occurrence of a torrid zone is peculiar to abnormal or glacial intervals.

Nearly a decade later Dr. Knowlton took up the subject with some thoroughness [4] and after discussing the several geological periods individually he said in summary:

[3] David White and F. H. Knowlton, "Evidences of Paleobotany as to Geological Climate," *Science*, N. S., Vol. 31, May 13, 1910, p. 760.

[4] F. H. Knowlton, "Evolution of Geologic Climates," *Bull. Geol. Soc. Amer.*, Vol. 30, pp. 499–566, 1919.

. . . It is perhaps not too much to say that it has now been demonstrated beyond reasonable question that climatic zoning such as we have had since the beginning of the Pleistocene did not obtain in the geologic ages prior to the Pleistocene. I think this statement of conditions is very generally accepted by geologists and paleontologists—in fact, I am at a loss to know how the data available can be otherwise interpreted.

Dr. Charles Schuchert also in discussing the climates of the past says:[5]

The marine "life thermometer" indicates vast stretches of time of mild to warm and equable temperatures, with but slight zonal differences between the equator and the poles. The great bulk of marine fossils are those of the shallow seas, and the evolutionary changes recorded in these "medals of creation" are slight throughout vast lengths of time that are punctuated by short but decisive periods of cooled waters and great mortality, followed by quick evolution, and the rise of new stocks. . . . On the land the story of the climatic changes is different, but in general the equability of the temperature simulates that of the oceanic areas. In other words, the lands also had long-enduring times of mild to warm climates. Into the problem of land climates, however, enter other factors that are absent in the oceanic regions, and these have great influence upon the climates of the continents. Most important of these is the periodic warm-water inundation of the lands by the oceans, causing insular climates that are milder and moister. With the vanishing of the floods somewhat cooler and certainly drier climates are produced. The effect of these periodic floods must not be underestimated, for the North American Continent was variably submerged at least 17 times, and over an area of from 154,000 to 4,000,000 square miles.

As regards the rate of diastrophic movement upon which so much depends in any estimate of geologic time for the reason that the processes of erosion, transportation, and deposition are all adjusted to it, something may be contributed tending to alter the prevailing view that such rate even approaches the slowness which has been supposed. The doctrine of uniformitarianism which came in with Lyell and which did away with the necessity for assuming sudden world cataclysms and replaced these in the minds of geologists by almost infinitely slow changes, brought with it the idea that changes of level of the outer shell of the lithosphere came about as gradual warpings extended over long periods of time.

Yet even Lyell had recorded in his "Principles" accounts of a number of earthquakes at the time of which considerable areas of land surface *suddenly* underwent changes of level measured in feet

[5] Charles Schuchert, "Climates of Geologic Time," Smith. Rept. 1914, pp. 277–311.

or in tens of feet. Today we know that there are large areas of the earth's surface which remain in a relatively stable condition, but that there are also well-marked zones within which mountains are rising, and where to the accompaniment of earthquakes, changes of level measured in feet or in tens of feet occur at intervals at least as often as once each century. The writer recalls vividly the shock to preconceived notions when Milne and Burton's album of photographs from the Japanese earthquake of 1891 came into the hands of geologists. To look at a vertical wall 18 feet in height separating a large uplifted section of a valley from its neighboring down-thrown portion, lay outside the experience of the geological profession. From that time, however, confirmation of such mutations of the surface came notably with the earthquake in British India of 1897, that in Alaska in 1899, and those in Formosa and California in 1906.

The instrumental study of remote earthquakes by means of the seismograph, which belongs to the present generation, has indicated that the number and the magnitude of diastrophic movements upon the land areas are few and small compared to those which occur upon the floor of the oceanic areas, particularly that of the Pacific Ocean and the Mediterranean and Caribbean zone athwart the Atlantic. The lack of an expeditious, accurate, and inexpensive method of sounding the seas has thus far prevented our securing evidence concerning the actual amplitude of these diastrophic movements upon the floor of the sea; but now with the invention by Dr. Hayes of the U. S. Navy Department,[6] of the sonic depth finder we already have in our possession the means of correcting this defect.

Largely unknown to us there is, however, an extensive body of fact bearing upon this subject of the unrest of the ocean floor—the so-called *vigias*—those mysterious perils to navigation which have been reported by some navigators, but sought for in vain by others. A preliminary investigation of such areas, usually represented upon the hydrographic charts by the symbols " E. D." or " P. D.," shows that they represent in many, if not in all, cases places of special unrest and the loci of seaquakes. They fall to a very large extent within those zones within which mountains are rising and troughs

[6] W. H. Hobbs, " Sounding the Depths of the Ocean," *The Michigan Technique*, Vol. 36, January, 1923, pp. 5–8.

being depressed in their neighborhood. Here there is good ground to believe that the floor of the ocean has undergone sudden changes of elevation measured individually not in tens of feet, as are the zones of unrest upon the continents, but rather in hundreds and even thousands of feet. Perhaps the most remarkable example of a vigia is that of St. Esprit Reef off the front of the Lesser Antilles. The history of this vigia extracted from the *West Indies Pilot* supplemented by data kindly furnished by the U. S. Hydrographic Office is as follows:

1723. *Automne* reports danger in this vicinity.

1817. *St. Esprit* reports chain of rocks distinctly seen in water 8 ft. deep for distance north and south of 500 fathoms and distance east and west of 100 fathoms. Lat. 14° 37′ N., Long. 58° 56′ W.

1833 (Feb.).
H. M. S. *North Star* en route Antigua to Demerara struck soundings at 7 fathoms near *St. Esprit* vigia.

1833 (Oct.).
H. M. S. *Dispatch* made soundings in passing near position, but found no shoal.

1834 (Jan.).
H. M. S. *Ariadne, Sapphire, Vestal, Forte,* and *Victor* searched for the shoal without result.

1836. *Galatea* also made search with negative result.

1866. H. M. S. *Buzzard* found banks with depths of 40–80 fathoms extending 10 miles from N.W. to S.E. and about 18 miles west of the original locality of St. Esprit vigia.

1866 (later).
H. M. S. *Wolverine* confirmed *Buzzard's* soundings.

1866–7.
H. M. S. *Gannet* searched for bank in vain.

1869. H. M. S. *Jason,* 1872, H. M. S. *Sirius,* searched for bank in vain.

1876. Danish brig *Venus* saw rocks in lat. 14° 40′ N., long. 59° 10′ W.

1898. H. M. S. surveying vessel *Rambler* searched for shoal in vain, but found soundings ranging from 1,440–1,940 fathoms.

1908. *Gallion* reported discolored water in lat. 15° 18′ 22″ N., long. 60° 4′ 53″ W. No soundings taken.

Latest hydrographic charts show depths in area to be from 1,540–1,968 fathoms.

Fig. 1. Sketch map showing the position of the St. Esprit Vigia in its relation to the mountain arc of the Lesser Antilles.

The facts as set forth above are not to be laid aside by any reference to possible errors of observation or of judgment. Startling as they are, they show that within a limited area, where a mountain arc is in process of erection, the ocean floor undergoes alternations of uplift and subsidence which are measured in thousands of feet for the period of at the most a few decades. Faults of this measure occur on the floor of the Mediterranean near Lante, Greece; and a throw of 600 feet on one of them took place during the sea-quake of October 26, 1873.

One other example calls for mention here. Off the eastern coast of the Australian continent, and similarly upon the convex margin

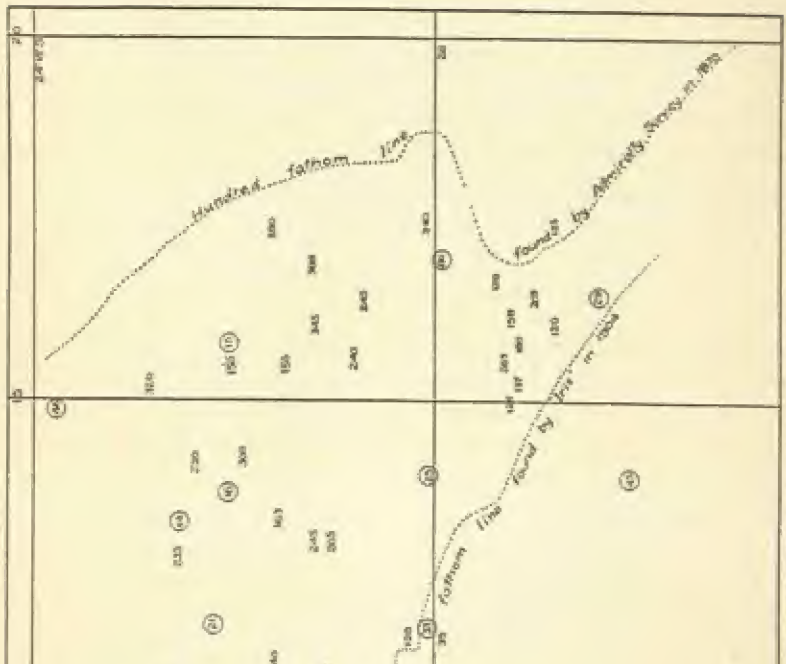


FIG. 2. Map to show changes in level in the neighborhood of Break-Sea Spit, Queensland, Australia. The figures in circles are the soundings in fathoms of the Admiralty Survey of 1870; the others are of 1904 (after Hedley).

of a rising mountain arc, there is an area of special unrest which has been described by Hedley.[7] Fraser's Island, Queensland, terminates northward in Break-Sea Spit and northward of this spit early navigators, including Cook and Flinders, reported the water of moderate depth. About 1869 this area was surveyed and accurately charted by the British Admiralty. Repairs required by a submarine telegraph induced Captain Sharp in H. M. C. S. *Iris* to make a reexamination of the area in 1904.

> He found that from five to ten miles north of Break-Sea Spit the conformation of the sea floor had entirely altered during the thirty-four years that had elapsed since the previous survey. Where his predecessors had found from twenty to thirty fathoms he measured from two to three hundred fathoms. The hundred fathom line had greatly changed both in direction and position.[8]

The map supplied by Captain Sharp and published by Hedley shows that over a large section of the area in question there has been an average subsidence during thirty-four years of more than one thousand feet. I am informed by Dr. Hedley in a personal communication that quite recently and since the later soundings were made the area has been the focus of a series of earthquake movements. The great importance of obtaining a new map of the area in even greater detail by the use of the sonic depth finder after an interval of almost a score of years must be apparent to all.

In another place it will be shown that the front of strongly curved mountain arcs which are now forming within the oceanic area are generally the loci of strong seaquakes as well as of alternating uplifts and subsidences of large amplitude.

UNIVERSITY OF MICHIGAN,
ANN ARBOR, MICHIGAN,
April 5, 1923.

[7] Dr. Chas. Hedley, Presidential address, *Proc. Linn. Soc. New South Wales*, Vol. 36, 1911, pp. 1–39.

[8] Hedley, l. c., p. 17.

DISCUSSION OF A KINETIC THEORY OF GRAVITATION II.; AND SOME NEW EXPERIMENTS IN GRAVITATION.

THIRD PAPER.

BY CHARLES F. BRUSH.

(Read April 20, 1923.)

The writer first outlined "A Kinetic Theory of Gravitation"[1] before the American Association for the Advancement of Science in December, 1910.

In April, 1914, he presented the first discussion of the theory to this Society.[2]

In April, 1921, he presented the first paper under the present title,[3] which consisted of a second discussion of the theory and some new experiments in gravitation.

The second paper under this title[4] was presented in April, 1922, and was devoted to pendulum experiments.

Following the pendulum experiments detailed in last year's paper, I constructed a new bismuth bob of the same diameter, height, and weight as the former zinc bob, for comparison with the latter.

The new bismuth bob consists of two carefully machined discs of equal thickness separated by a thinner disc of parafined wood as shown in Fig. 1. The three discs are securely fastened together by four slender brass screws, two from each side symmetrically located, and tightened up while the whole was hot enough to melt the free paraffin on the surface of the wooden disc. Final machining of the compound bob was done after the parts were permanently assembled. This bob was adjusted with great care for parallelism of ends, exact equality in height with the zinc bob, and location of center of gravity

[1] *Science*, March 10, 1911; *Nature*, March 23, 1911.

[2] PROC. AM. PHIL. SOC., Vol. LIII., No. 213, January–May, 1914.

[3] PROC. AM. PHIL. SOC., Vol. LX., No. 2, 1921.

[4] PROC. AM. PHIL. SOC., Vol. LXI., No. 3, 1922.

exactly midway between its faces, all as heretofore described in connection with other bobs. Also, the center of gravity was adjusted to lie accurately in the axis. The weight and centers of gravity adjustments were made by drilling small cavities in either face, which were then filled with paraffin to a smooth surface, as were also the small cavities at the heads and tips of the screws. The weight of the

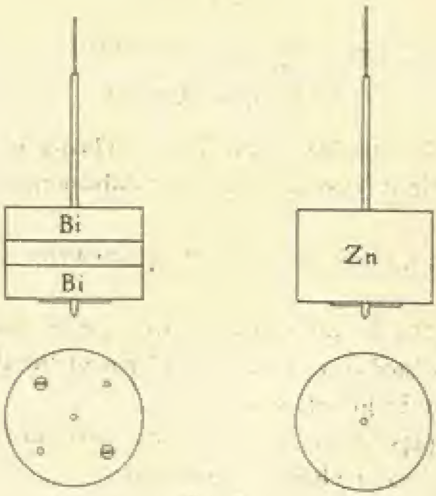


FIG. 1.

paraffin fillings was made to be a part of the total adjusted weight.

The compound bismuth bob was then most carefully compared in performance with the former zinc bob, in the manner described in the last two papers, using the long pendulum rods.

The purpose of these experiments with bobs of the same *size*, as well as weight, was threefold: 1st, to eliminate difference of air resistance entirely; 2d, to eliminate almost wholly (not quite) the very large radius of gyration correction formerly necessary on account of the considerably different diameters of the zinc and bismuth bobs; 3d, to test the effect of elimination of difference in air displacement. For certain reasons it was believed that the effect of difference in air displacement canceled out in the former pendulum experiments. And its computed value, if it did not cancel out even in part, was quantitatively so different from the observed zinc-bismuth effect that it

could not account for the latter, but could only reduce its quantitative value. The latter proved to be the case; the apparent zinc-bismuth effect was reduced about two thirds. But this does not matter because, as pointed out in the last paper, the end sought in these experiments is not quantitative value, but qualitative certainty. Moreover, as surmised in that paper and shown later in the present paper, physical condition of some metals appears to have much to do with their mass-weight relationship. This seems to be conspicuously the case with zinc. And again, as will appear toward the close of this paper, manifestation of mass-weight differences between various substances appears to depend very much on the method employed to exhibit it.

Following the pendulum experiments above detailed, 3 more bobs were made respectively of lead, bismuth, and "fusible alloy." The latter consists of 15 parts bismuth, 8 parts lead, 4 parts tin, and 3 parts cadmium. This alloy was chosen because its specific gravity differs but little from that of bismuth, and not much from that of lead; and because other experiments, detailed later, had shown that the alloy, and also bismuth, differ considerably from lead in mass-weight relation.

The 3 bobs, shown in Fig. 2, were made of the same diameter,

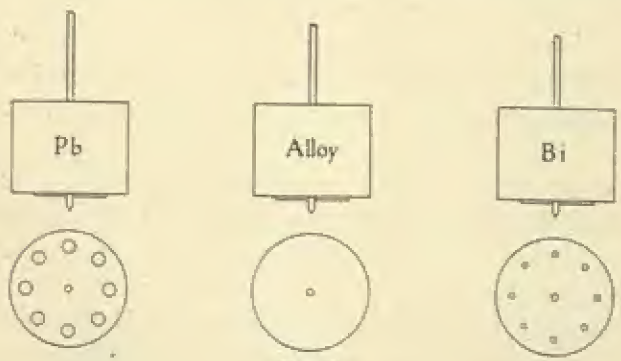


Fig. 2.

and carefully adjusted to the same height, with center of gravity midway between faces as usual. Equality of weight was effected by drilling 8 small holes through the bismuth parallel with its axis, and having their centers in a circle of such radius that as much metal lies

within as without the circle. The lead bob was drilled in the same manner, but with larger holes. All holes were closed at both ends with shallow corks dressed smoothly to the general surface.

The new bobs were repeatedly compared on the long pendulum rods, with the following results: Lead was found faster than alloy by one part in about 150,000, and faster than bismuth by one part in about 170,000. Difference between alloy and bismuth was too small to be detected with certainty. Under the conditions of these experiments no corrections of the above results are indicated.

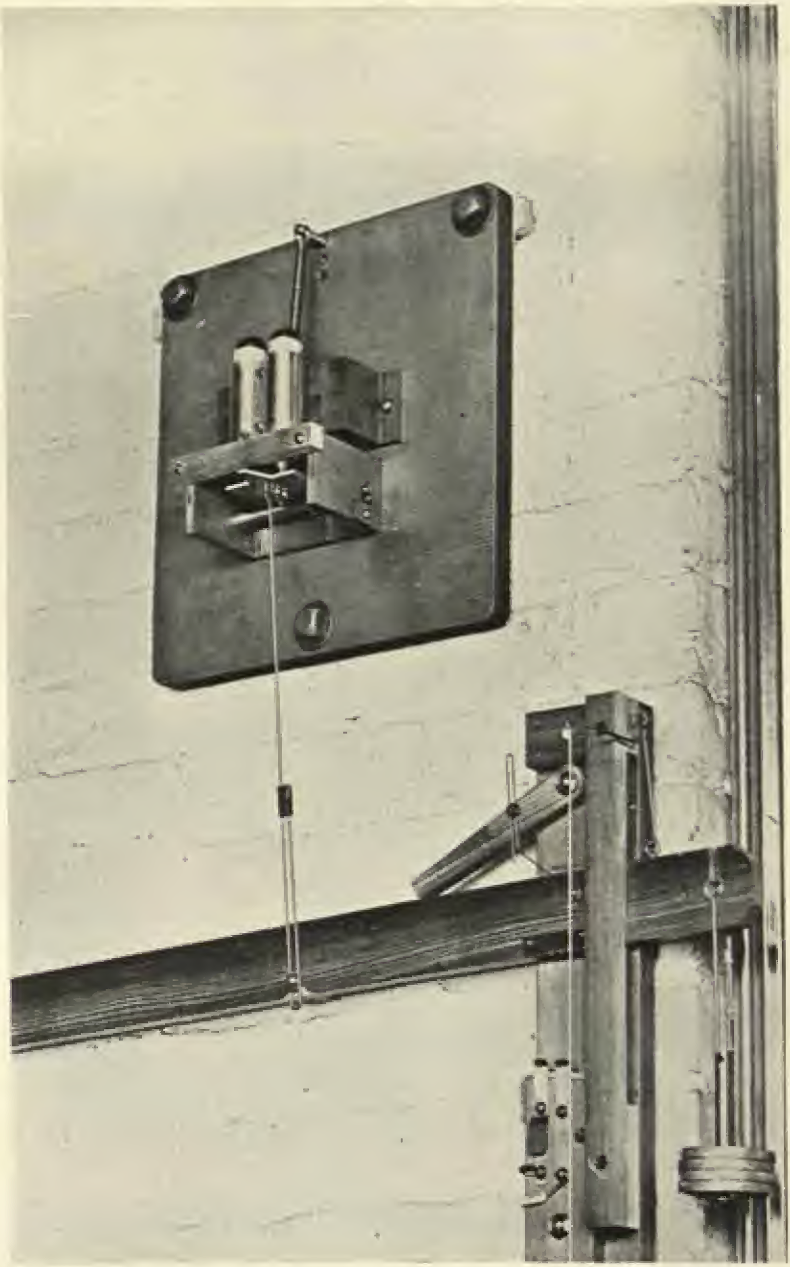
Aside from the foregoing pendulum experiments, the past year has been fully occupied in developing two other quite different lines of experiment, both requiring most carefully designed and constructed apparatus of precision, and both yielding very satisfactory affirmative results.

One of these methods consists in photographic observation of cumulative amplitude differences between zinc and bismuth or other substances, when they are successively used as the oscillating load on a long spiral spring, under exactly the same conditions of weight, air resistance, and air displacement. This method is complex in theory and slow in practise, but gives excellent results. I shall reserve a description of it for a future paper.

The other method is quite simple in theory and very rapid in practise. It consists in comparing the velocities of freely falling bodies in two aluminum containers, alike in size, shape, and smoothness of surface.

The containers are partly or wholly filled with the two substances to be compared, and to the same total weight to equalize air-resistance effects, and dropped simultaneously, side by side, from exactly the same height always.

After falling about 122 cm. (4 feet) the containers strike a pair of horizontal targets exactly equidistant from their starting points. The adjustment for equality of falling distance is made by loading both containers with the same substance and dropping them in reversing position again and again while adjusting the level of the targets until the containers strike the targets simultaneously. The mechanism is such that the containers push the targets downward and back-



ward out of their path after striking them, and are then caught and stopped in a hollow wedge-shaped receptacle lined with very thick felt.

When, however, the containers are equally loaded with substances having different *mass-weight* relationships, such as lead and tin for instance, the one having the less mass per unit of weight (lead in this instance) will acquire a higher velocity in falling than the other container, and will strike its target in advance of the other.

The method of observing which container strikes its target first is extremely simple and effective, as follows: Each target when struck breaks an electric circuit between a platinum point and plate; but *both* target breaks are *in series* in the *same circuit*, so that there is a bright spark at the break which occurs first, and none at the later break because its circuit is already open. To make this scheme effective for very small time differences, say a four hundred thousandth part of a second or less, it is only necessary to have a rather large current, for brightness of spark (12 to 15 amperes is ample), and as little inductance as possible in the circuit, to keep the spark very short. To these ends the wiring is heavy, so as to put most of the circuit resistance in the platinum contacts, and is paralleled as far as possible. Two dry cells of battery or one storage cell give ample e.m.f.

Plate I. shows the complete apparatus ready for use. Two cast-iron plates, 30.5 cm. square and 2 cm. thick, with machined surfaces, are securely bolted to a thick brick wall with their faces in the same vertical plane. The upper plate carries the mechanism for holding, guiding, and releasing the containers. Below this plate may be seen the starting and circuit closing device ready to be tripped by pulling a cord hanging from it. The lower plate carries the target and sparking mechanism; and below it is seen the felt-lined receptacle for stopping the falling containers.

Plate II. is an enlarged view of the releasing mechanism with the loaded containers in place, ready to start simultaneously on their downward journey, and Plate III. shows the same mechanism after the containers have been released and have fallen. It also shows the starting device locked against rebound and the sparking circuit closed.

Plate IV. is an enlarged view of the target and sparking mechanism ready to receive the falling containers, and Plate V. is the same after the containers have passed through it.

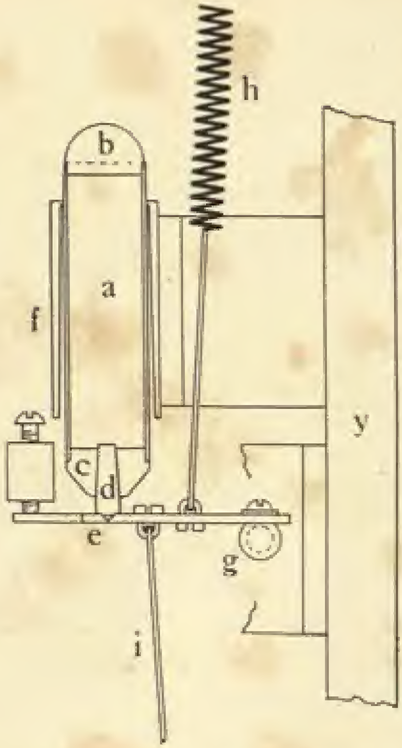
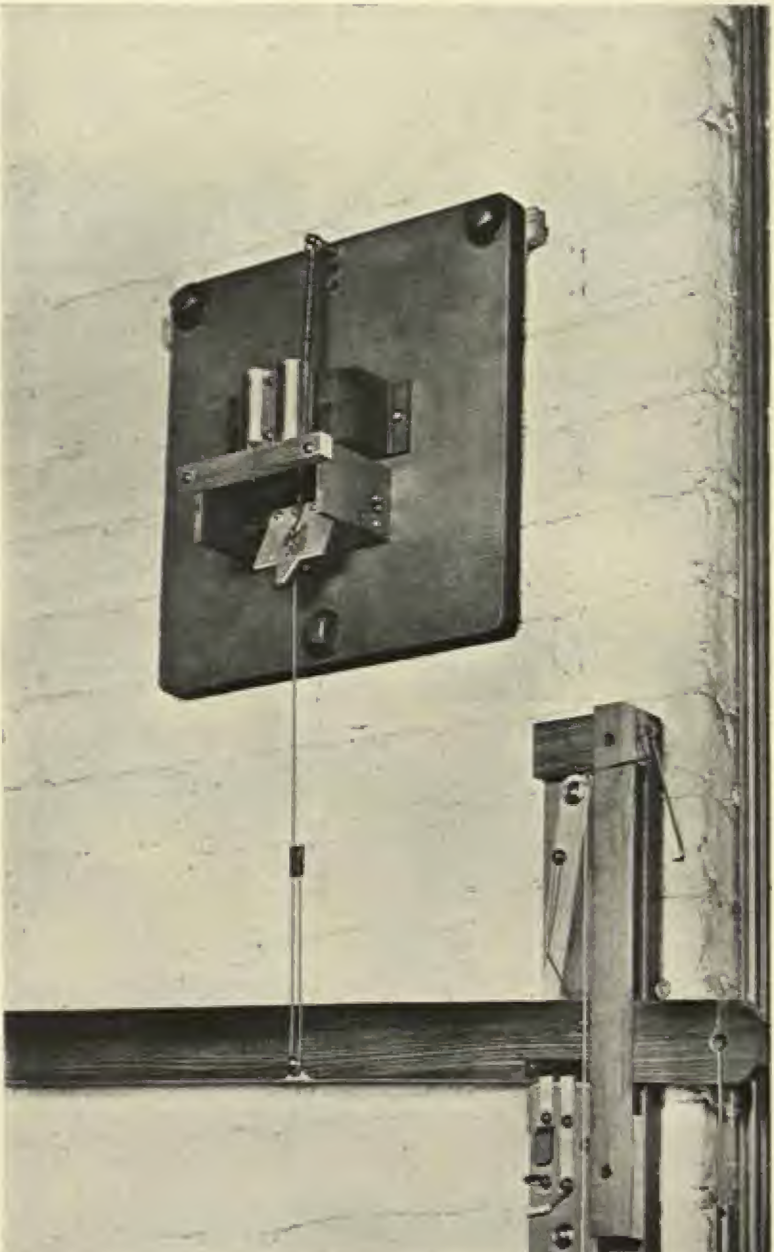


FIG. 3.

Fig. 3 is a diagram of the dropping, or releasing, mechanism in vertical side section through axis of the right-hand container shown in Plate II. The container *a* is made of aluminum tubing 8 cm. long and 2.2 cm. and 2 cm. outside and inside diameters. The upper cm. of the tube is tapered smaller, and the tube is capped by a snugly fitting dome-shaped plug of hard rubber *b*, easily removable for loading the container. The lower end of the tube is permanently closed by a forced-in aluminum plug *c*, through which passes the firmly driven conical brass stud *d* projecting above the plug, and on which rests any cylinder of metal with which the container may be loaded. The lower end of brass stud *d*, after machining, to center it, was ground and polished like a lens, to a radius of 6.5 mm. It rests on the open end of a smaller conical cavity in the thick aluminum plate *e*



permanently adjusted to horizontal position. The open end of the conical cavity is ground to the same radius as the brass stud, so that the latter contacts with the plate in a narrow ring.

The container *a* is held in truly vertical position by the guide tube *f*, which is slightly conical inside and, at the last mm. of its upper end, just freely fits the container at the point where the latter begins to taper. The inside of the guide tube at its upper end, as well as the container, are polished; and as there is no side thrust on the container, friction between it and the guide tube is virtually zero. Moreover, owing to its tapered upper end, the container is absolutely free after the first mm. of its fall.

The plate *e* is firmly attached to the brass axle *g* by 4 screws. The axle has smaller end bearings pulled firmly upward against inverted V bearings by the stiff spring *h*. This spring also holds up both loaded containers with a safe margin to spare. Thus the mounting of the axle *g* is like that of a transit instrument inverted, and there is no lost motion in its bearings.

When it is desired to leave the containers free to fall, the starting mechanism shown in Plates II. and III. is tripped and the plate *e*, common to both containers, is jerked suddenly downward and then to the right by the rod *i*, much faster than the containers can follow by gravity. This is because the starting lever and weights at its right-hand end fall some distance and acquire considerable velocity before taking up the slack in the link at the lower end of rod *i*.

The guide tubes *f* and the mechanism of plate *e* are mounted on separate brass cradles very firmly screwed to the heavy cast-iron plate *y*. Hence any jar due to the sudden jerking downward of plate *e* is not directly communicated to the guide tubes.

Fig. 4 is a plan and side elevation of the receiving target mechanism shown in Plates IV. and V. The targets *l* are of spring-tempered steel .72 mm. thick, and very firmly screwed to the axle *m*, with their centers 3.2 cm. apart. The axle *m* is made of strong but light aluminum alloy to reduce its inertia, because it must start a partial revolution very suddenly when the targets are struck by the falling containers. The axle turns in inverted V bearings at its ends, like those of the dropping mechanism already described, and is held up

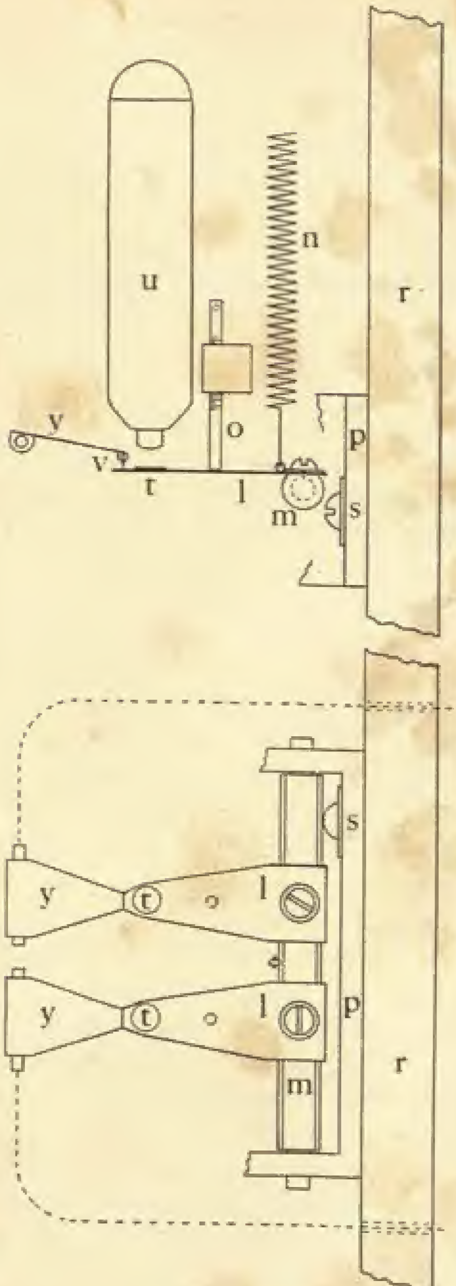
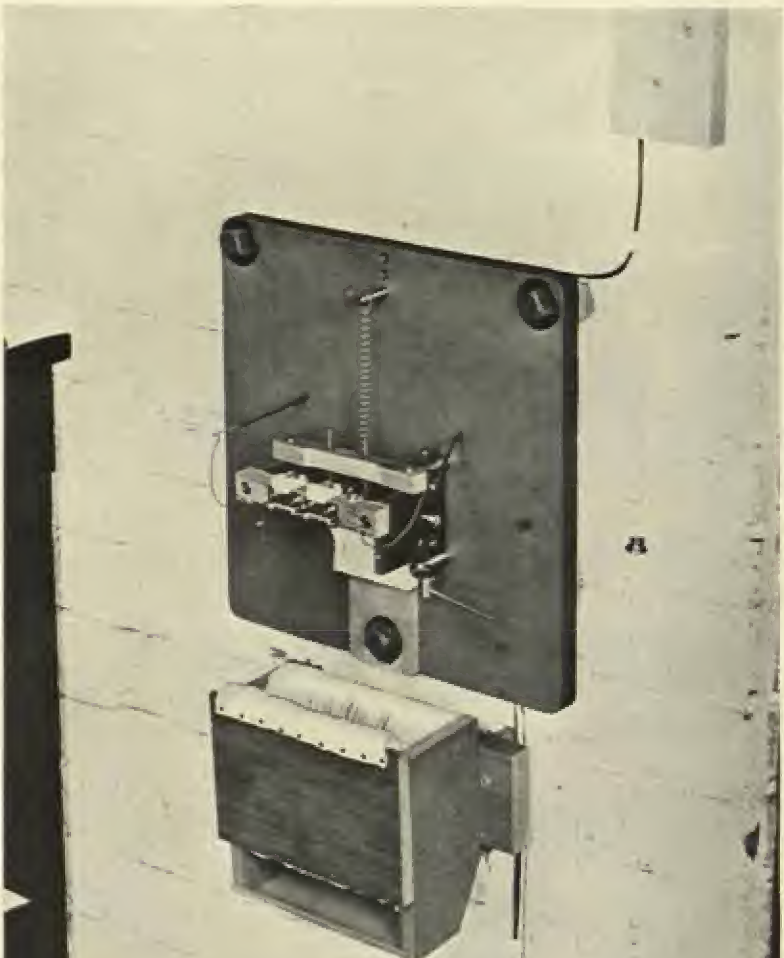


FIG. 4.



in its bearings by the soft spring *n*, which also holds the targets against the leveling screws *o*. These screws are adjusted to bear with about equal pressure against the springy targets, and require no further attention.

All the target mechanism is carried in a brass cradle *p*, which fits closely and accurately against the machined vertical surface of the cast-iron plate *r*, to which it is snugly but movably held by the screw *s* and a stiff spring washer. The screw *s* is seated in the end of a brass gudgeon securely anchored in the iron plate, and accurately fitting a boring in the cradle, so that the cradle may be slightly rocked on the gudgeon without any lost motion at that point.

The right-hand end of the cradle *p* (as seen facing it) is adapted to be slightly raised or lowered by a tangent-screw below, opposed by a stiff flat spring above, so as to adjust the relative level of the right and left targets. The tangent-screw has a capstan head and long lever for fine adjustment, seen in Plates IV. and V.

As the targets are elastic and their relative motion but a fraction of a mm., it is entirely practicable and highly convenient to mount them on one axle common to both, as shown.

The targets are strongly tapered at their free ends to make them as light as practicable, and thus reduce the shock of impact when the falling containers strike them. To this end also, "shock-pads" between the targets and lower terminal studs of the containers are *always* used. Without these pads the striking parts would soon be battered out of shape.

The most satisfactory kind of "shock-pads" are small thin discs *t* of soft lead about half a millimeter thick. As these pads can be used but once, they are made in quantities of a thousand or more, of accurately the same thickness, by punching them from sheets rolled a little thicker than the finished pads, and then putting them through the rolls, set a little closer, *at the same point on the rolls*, one at a time. This gives the pads a slightly oval shape, and such uniformity of thickness that no differences can be detected with a delicate micrometer caliper. It is essential that the "shock-pads" be carefully placed so that impact of the container studs shall be at their centers.

u indicates a falling container about to strike its target, with a shock-pad *t* interposed. The force of impact is from 5 to 6 kg., as found by comparing the imprints on the pads with others produced by static pressure; and the impact varies but little with large changes of load in the containers. With earlier and heavier targets the force of impact reached 18 kg.

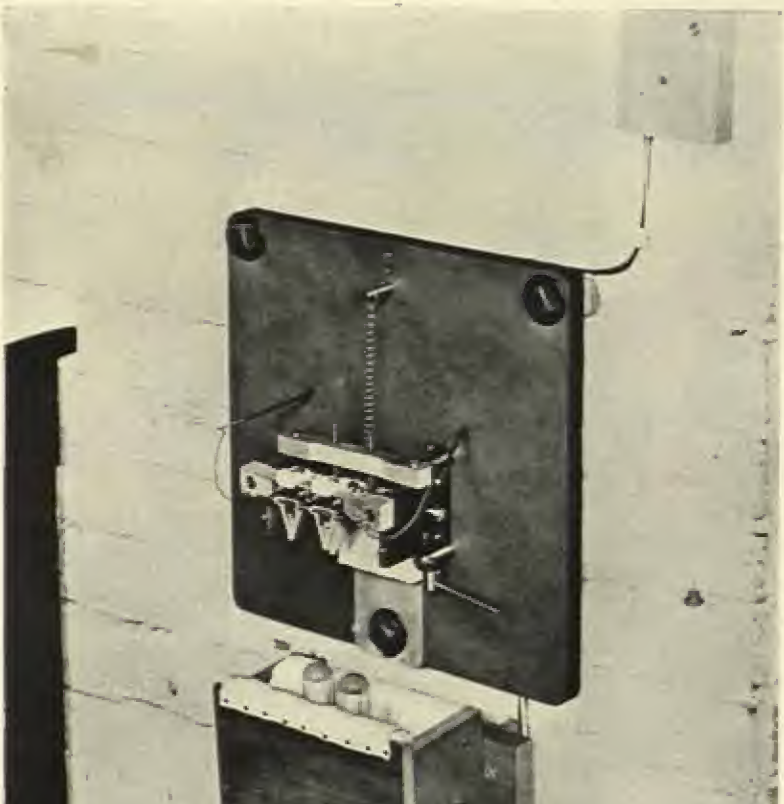
Near its extreme tip each target has a large platinum rivet or inset dressed flush with its upper surface, and on which the pointed platinum wire *v* rests, making the electric contact which, when broken, shows the spark. Each platinum wire has a light aluminum carrier *y*, adapted to be knocked downward and sideward out of the way by the container *u* *after* the sparking contact has been broken by the very sudden downward motion of the target. At the instant of breaking either contact its *independent* point carrier is held virtually stationary by its own inertia.

Buffers of thick white felt, seen in Plates IV. and V., arrest the very rapid motion of the carriers and targets; and the latter are prevented from returning by a spring catch (not seen).

The dotted lines indicate the wiring and path of the electric current through the target sparking contacts *in series*. One of the containers is marked with a white spot at the top for identification.

Thus far the performance of this apparatus has proved quite trustworthy and very satisfactory. Since installation of the targets above described the two containers, loaded, have been dropped more than a thousand times, and there has been no marked irregularity of action or sign of failure in any part.

Each container weighs about 31.5 grams, and their loads may vary from about 30 grams in the case granulated aluminum filling one of them to 2 or 3 times that much in cases of heavier metals. And, of course, *both* containers are never filled because of differences in volume of their equally heavy loads, as, for instance, in the comparison of granulated aluminum and lead sawdust, or both metals in the form of cylindrical castings. Unequal air displacement is of no consequence even if it were necessary to make the loaded containers exactly equal in weight, because the inclosed air is a part of the load. But close equality in weight is not necessary; an intentional difference of



1 per cent. did not materially affect the result when tried. Yet their weights are always made equal within 3 or 4 mgs. because it is so easy to do this.

In using the apparatus the procedure is as follows: The target levels having been approximately adjusted as already indicated, or left so from a previous experiment, the containers, loaded with equal weights of the substances to be compared, say lead and tin for instance, are simultaneously dropped and the bright spark at the right or left target is noted. For convenience the sparks are viewed in a diagonal mirror. Then the containers are reversed in position, the former right one now being the left, and dropped again, the location of the spark being noted as before. This is repeated several times for confirmation.

In the case of lead and tin, as above, the container loaded with lead will produce the spark every time, alternately at the right and left target, even when the target levels are not closely adjusted; clearly showing that the lead-loaded container falls faster than the other and reaches its target first, whichever target that may be.

In the earlier experiments it was customary to exchange the loads in the containers after a set of trials as above, and go through the procedure again, as a check against difference in behavior of the containers. But no difference was observed.

When two similarly behaving substances are compared, such as a cast lead cylinder and an equal weight of lead sawdust, no delicacy of target adjustment will make the spark consistently favor either container. And when the adjustment is very close, minute sparks may occasionally appear simultaneously on both sides. In such a case of close adjustment a very slight change of relative target levels is sufficient to give a large preponderance of sparks to one side. Thus, if either target is raised by the tangent-screw so little as a two hundredth of a millimeter, it will become the sparking target, now getting a large majority of the sparks. Possibility of such fine adjustment is cited to show the high sensitiveness of the apparatus.

When container velocities differ considerably, say one part or more in 50,000, that fact is demonstrated in a few minutes; and approximate measurement of the difference is made as follows: A

small disc of hard-rolled paper is placed on one target under the lead "shock-pad" which is to be struck by the *slow* container at the next dropping, and this is repeated several times, with reversals of containers as usual, until it is demonstrated that the paper is too thick or too thin to bring about simultaneity of target striking. Then, as may be indicated, thicker or thinner paper discs are tried; and so on, until the right thickness is found, or as is usually the case, until the right thickness is demonstrated to lie between two of those tried, which may differ only .01 or .02 mm. Then the right thickness is estimated, often nearer one than the other as the sparks may indicate. Paper discs are used (only once) because their weight is negligible and they are easily prepared.

Such a measurement of relative velocities of the containers attained during the half second of their fall may require 30, 40, or 50 droppings, depending on luck in choosing thicknesses of paper for trials. But considerable aid is furnished by the character of the sparks, which grow less bright as simultaneity is approached. The probable error in such measurements need not exceed .01 mm. or one part in 122,000.

Inasmuch as the substances whose accelerations are being compared constitute much less than the whole weights of the loaded containers, measurements as above obtained must be corrected (increased) to allow for the containers which take no part in the differences observed.

Of the several metals thus far rather carefully compared, lead is the fastest in falling; then come bismuth, fusible alloy, perhaps zinc, tin, and aluminum in the order named. Zinc is uncertain in location because its velocity seems to vary considerably with its physical condition, as will appear.

The difference in velocity between lead sawdust and granulated aluminum was found to be something like one part in 10,000; and an aluminum casting, filling the container, was *considerably* slower still.

The difference in behavior of the aluminum loads may be caused by physical condition, or by eddy currents in the long and highly conducting casting, due to its accelerating motion through the earth's

magnetic field. Undoubtedly eddy currents are always set up in the highly conducting aluminum containers; but as these fall through the same field and are equally conducting, no observable difference in retardation has been found; and probably generation of eddy currents is confined to the shells of the containers. Of course, such currents can not occur in granulated metal or sawdust.

To test the effect of dropping the loaded containers through a distorted magnetic field, a rather feeble bar magnet 24 cm. long was placed horizontally in the plane of the falling containers with its nearer pole 10 cm. to the right of the center of path of the right-hand container, and about three fourths of the way down that path. Unequal retardation of the containers was quite apparent. But the effect of this was wholly eliminated by raising the right target about .01 mm., after which all went on as before.

The diagram of the sparking circuit in Fig. 4 shows there must be two equal fields just above the targets, through the adjacent edges of which the lower ends of the containers fall. But these fields are quite symmetrical, and being of the same polarity tend to repel and neutralize each other, so that no unequal disturbing effects can arise.

Pure amorphous iron, reduced by hydrogen, in one of the containers, which must have distorted locally and greatly the earth field through which it fell, behaved much like tin, though this probably does not indicate its proper position in the scale.

It has been very gratifying to find that massive cylinders of metal in firm contact with the brass studs of the containers are not necessary, and this greatly extends the field of usefulness of the apparatus. Thus a cast lead cylinder and an equal weight of lead sawdust showed no difference in behavior. And the same was true of bismuth and bismuth sawdust; though different specimens of commercial bismuth behaved somewhat differently. Tin and tin sawdust were nearly alike. But the case was quite different with zinc. Several specimens of zinc sawdust from the same slab of electrolytic metal, but made at different dates, with saws of different coarseness, and with purposely different forcing or brutality of sawing, gave considerably different results. Only one of these behaved like a zinc casting. Two of the sawdust specimens, rather largely different in behavior, were taken

from the containers, put in test tubes, and heated in a muffle furnace several hours to 320 degrees C., then allowed to cool with the furnace. Their difference in behavior was but little changed.

From the above experiments with zinc, it seems highly probable that physical condition has much to do with mass-weight relation in that metal. And it is believed that this accounts largely, if not wholly, for the puzzling experience with zinc and bismuth cylinders used in the earliest experiments, and alluded to near the close of last year's paper. Thus the earliest targets were much heavier and more rigid, and their battering action on the cylinders in the containers was great. The superior speed of the bismuth was well marked at first, but after many trials gradually disappeared. Then after some weeks of rest, during which new and better targets were installed, the bismuth was fast again, but only for a time. This occurred repeatedly.

A lengthy course of very careful experiments strongly tended to show, but not conclusively, that bismuth, under certain conditions of repeated strong shock, changed in weight appreciably; but further shocks often changed it back again, or even reversed the sign.

For many years there has been a general belief that the classical experiments of Eötvös demonstrate the general proposition that mass-weight ratio is the same for all substances, and that the slight departures found must be due to experimental errors. Eötvös assures us that mass-weight ratios of brass, glass, antimony, and cork differ less than 1/20,000,000; and glass and air less than 1/100,000. Professor H. A. Wilson, by the same method,[5] finds that bismuth and aluminum differ less than 1/1,000,000.

The theory of the Eötvös experiment, as I understand it, is as follows: The centrifugal force of the earth's rotation acts on matter in a direction normal to the earth's axis; this is mass action. But the far greater and opposing gravity action is toward the earth's center. The angle between the two forces is measured by the latitude of the place of experiment. The resultant of the two forces acting at an angle is a small horizontal component in the direction of the equator. This is generally recognized as the cause of the earth's oblate figure.

If, now, we have a tension pendulum with a long and very fine

[5] *Phys. Review*, N. S., Vol. XX., No. 1, July, 1922.

wire or quartz filament suspension, and short horizontal arms loaded at their ends with two small bodies having different mass-weight ratios, the one having the greater mass ratio will have a very small residual horizontal component acting toward the pole. If we start with the two bodies in an east and west direction, this minute residual force will tend to twist the suspension wire, and the amount of torsion can be read by mirror and scale forming integral parts of the apparatus, when the whole is revolved 180 degrees about a vertical axis; which is the same thing as exchanging the loads. (Of course, this procedure will double the real angle of torsion.)

The Eötvös method, while beautiful in theory, appears to be almost wholly barren of affirmative results. Perhaps this is due to the fact that in it there is no real acceleration—acceleration in the sense of changing velocity and changing momentum.

In the pendulum experiments, however, there is real acceleration, alternately positive and negative. As I view the matter, this means alternating absorption and restitution of free energy of the ether, the sort of energy acquired by falling bodies. But the rise and fall of the bobs is small, and being greatly restrained, is slow in time, so that manifestation of mass-weight differences is much restricted.

But in the free-fall experiments described in the present paper the accelerating action of gravity is unrestrained, and manifestation of mass-weight differences becomes comparatively very strong.

Cleveland, Ohio,
April, 1923.

THE EXPLORATIONS OF THE AMERICAN MUSEUM OF NATURAL HISTORY IN CHINA AND MONGOLIA.

By HENRY FAIRFIELD OSBORN.

(Read before the Philosophical Society April 20, 1923.)

Roy Chapman Andrews, leader of the Third Asiatic Expedition of the American Museum of Natural History, was prepared for his very responsible task by several preceding years of exploration in China. The territory he explored in 1922 had been crossed by Raphael Pumpelly in 1862–65; by Obrutchev in 1892–1894, who applied the name "Gobi Series" to the later sediments; and by Chernov in 1908. Similar territory farther south was crossed also by von Richthofen in 1877, and it was he who gave the name Khan-Khai beds to the later sediments found in the desert region. The underlying series, from the Jurassic downwards, as developed in China, had been described by von Richthofen and later by Bailey Willis in his "Researches in China," 1907.

The geologic personnel of the Expedition included Charles P. Berkey as Chief Geologist; Frederick K. Morris as Geologist and Topographer; Walter Granger as Vertebrate Palæontologist. The entire personnel under Leader Andrews included a party of twenty-five, eight Americans, eight Chinese, nine Mongolians. By means of a train of seventy-five camels and two freight and three light automobiles, a three-thousand mile reconnaissance was made, as indicated in the accompanying map, between April 18 and September 20, 1922, when the party returned to Peking. The work was greatly aided by the Geological Survey of China, now under the management of Dr. V. K. Ting, Honorary Director, and Dr. W. H. Wong, Acting Director, with headquarters in Peking.

The itinerary of the party and series of fossil field discoveries are briefly stated by Professor Berkey as follows:

Left Kalgan April 21.

Went into camp at Iren Dabasu after finding rhinoceros jaw evening of April 24.

First dinosaur bones found at Iren Dabasu morning of April 25 by Berkey before breakfast.

Camp was divided April 25, leaving the geological group, Morris, Granger, and Berkey, at Iren Dabasu, giving special attention to the collecting of fossils.

First finds of Titanotheres and other Early Tertiary fossils by Granger at Irdin Manha April 27.

Additional finds made at Irdin Manha by the geologic group May 2.

First Baluchitherium bones found at Houldjin, in the vicinity of Iren Dabasu, April 30, by Berkey.

Geologic group stayed at Iren Dabasu until May 7, making a map and collecting fossils.

Basin later referred to as Tsagan Nor Basin was entered first at Mt. Uskuk June 21 by the whole party.

First exploratory trip to Loh June 22 by the geologic group, with recovery of a few fragments of bones.

Discovery of dinosaur bones and fossil insects and fossil fish June 25 in the Ondai Sair locality by Berkey and Morris.

Great collection of Later Tertiary fossils (judged to be of Miocene age) made by Granger and party at Loh in the Hsanda Gol formation, June 27–August 3.

Discovery of *Baluchitherium* skull at Loh August 4 or 5 by Granger and Wong.

Discovery of Stag, Mastodon, etc., judged to be of Pliocene age in the Hung Kureh District July 27 by Berkey. Whole group made collections later.

Left the Tsagan Nor Basin August 13.

Discovery of Dinosaurs in the Ashile District by Granger August 20–27.

Side trip to the Gurban Saikhan across a new basin by Morris and Berkey August 19–27, with recovery of a few fragments of bones.

Discovery of *Protoceratops* by Shackleford at Dja-doch-ta September 2. Additional collections by the whole party.

Discovery of Paleozoic strata with Permian fossils September 7 in the Sair Usu District by Berkey and Morris.

Discovery of Ardyn Obo fossil-bearing beds of Miocene age September 10. Collections by the whole party.

Discovery of Eocene forms in the sedimentary beds of Shara Murun by Granger and Andrews September 14.

Discovery of fragments of bone in the sediments at the edge of the Mongolian plateau above Kalgan by Berkey September 19.

The geologic party found a Great Unconformity separating the folded sediments of Jurassic and earlier time from all of the desert basin sediments. Even before the Jurassic Period the marine sediments of the roof of the world had ceased. Through the Jurassic and also above the Great Unconformity the sediments are entirely epi-continental. The series underlying the Great Unconformity from the Archæan to the Jurassic have been recognized by Willis in

GENERALIZED·GEOLOGIC·COLUMN·FOR·CENTRAL·MONGOLIA

BERKEY, MORRIS, GRANGER 1922	CENOZOIC	PLEISTOCENE PERIOD OF EROSION						
		UPPER TERTIARY	TSAGAN-NOR SERIES	LATE PLIOCENE	HUNG KUREH Form'n. (Stag, Mastodon, Struthiolithus, etc.)	GOBI SERIES OF OBRUCHEV ( )	KHAN-KHAI BEDS OF VON RICHTHOFEN (1877)	EPI-CONTINENTAL SEDIMENTS
				MIOCENE	HSANDA GOL Form'n. (Bal) HOULDJIN Form'n. (Bal) ARDYN OBO Form'n. (Rhin)			
		LOWER TERTIARY	UNNAMED SERIES	OLIGOCENE	IRDEN MANHA Form'n.			
				EOCENE	SHARA MURUN Form'n.			
	LATE MESOZOIC	UNCONFORMITY						
		UPPER CRETACEOUS LOWER CRETACEOUS		SHAMO SERIES	IREN DABASU Form'n. ONDAI-SAIR Form'n. ASHILE Form'n. DJA-DOCH-TA Form'n.			
		GREAT UNCONFORMITY						
EARLY MESOZOIC		JURASSIC (?)	TSETSENWAN SERIES (WILLIS, OBRUCHEV)					
LATE PALEOZOIC		PERMIAN CARBONIFEROUS DEVONIAN (?)	SAIR-USU SERIES (BERKEY & MORRIS)					MARINE SEDIMENTS
EARLY PALEOZOIC		MISSING						
		GREAT·BATHYLITHIC·INVASION (BERKEY & MORRIS)						
NEO-PROTEROZOIC		NAN-K'OU SERIES (WILLIS)						
		GREAT UNCONFORMITY						
EO-PROTEROZOIC		WU-T'AI SYSTEM (WILLIS)						
ARCHEAN		T'AI-SHAN COMPLEX (WILLIS)				DIVISIONS·ESSENTIALLY THE·SAME·AS·GIVEN·BY BAILEY WILLIS FOR·CHINA.		

China, and that pioneer work was a great help to the geologists of the Expedition. The Nan-K'ou Series of China seems to be continued across Mongolia. A great bathylith was found invading these older metamorphic rocks and is extensively exposed by erosion. It is on this complex erosion floor that all of the later strata were laid down, some of which were again swept away in the Post-Jurassic erosion interval. The Later Mesozoic and Cenozoic sediments of Mongolia lie upon the peneplaned surface of this complex of old deformed rocks with its Great Bathylithic Invasion.

This is a wide contrast to conditions in the Rocky Mountain Plateau region of America, where marine sedimentation continues to the very close of the Cretaceous and the Tertiary sediments overlie either the Cretaceous or the Jurassic.

On reaching the confines of Mongolia, Berkey and Morris began a systematic and continuous route map and geologic cross-section which was carried throughout the whole itinerary. These studies early in the work determined the major structural and formational units and located the major unconformities and other physical changes. The great Post-Jurassic Unconformity, the Pre-Jurassic Unconformity, the lesser Post-Cretaceous Unconformity, and the Great Bathylithic Invasion were one after the other definitely distinguished. Above the Great Post-Jurassic Unconformity ten new formations were thus differentiated and more or less clearly distinguished from each other by their vertebrate remains, on which determinations were made by Granger; four of these are in the Cretaceous, two at the confines of the Eocene and Oligocene, three in the Miocene, one in the Pliocene.

Summary of Fossil-bearing Formations Discovered.

1 Permian....................	with marine invertebrate remains.
1 Jurassic....................	with plant remains.
1 Lower Cretaceous...........	including the Dja-doch-ta Protoceratops Zone.
3 Cretaceous with more precise position not yet determined...	including the Iren Dabasu and the Ashile Dinosaur beds, as well as the Dinosaur and insect-bearing beds of Ondai Sair.

1 Upper Eocene	Protitanotherium Zone.
1 Lower Oligocene	(exact relations not yet determined.)
2 Middle Miocene	Baluchitherium Zone.
1 Miocene	not yet accurately related by fossil determinations.
1 Pliocene	the Hung Kureh Cervus Zone.
1 Pleistocene	an erosion epoch.

The only precedent to this reconnaissance in the geologic history of the arid regions of the world is to be found in the early surveys of our own western territories by Hayden as geologist and chief, Holmes as topographer, and Leidy as vertebrate paleontologist.

American Museum of Natural History,
New York.

CONTACT METAMORPHISM IN THE WESTERN ADIRONDACKS.

By WILLIAM M. AGAR.

(*Read April 20, 1923.*)

This paper attempts to establish the origin and geological relations of certain minerals of northwestern New York. The literature contains many purely mineralogical descriptions of these minerals, so that the question of crystal forms, etc., has not been touched upon.

The region examined lies on the northwestern edge of the Adirondack Plateau of northern New York State, west of the heavily forested area, between latitudes 44° 15′ and 44° 35′; and longitudes 75° and 75° 45′. It is contained within the limits of St. Lawrence, Jefferson, and a corner of Lewis counties, and includes parts of the following quadrangles: Hammond, Lake Bonaparte, Gouverneur, Russell, and Canton.

The field work was done during the summer of 1920, and the data collected then were studied during the two following winters.

The writer is greatly indebted to Professor C. H. Smyth, Jr., under whose direction and supervision this report has been prepared; to Professor A. H. Phillips, for two complete analyses, and for his help in discussing mineralogical details; and to Professor A. F. Buddington, whose assistance and suggestions, both in the field and in the laboratory, have been invaluable.

The writer was further assisted in the quest for mineral localities by directions furnished by Professor Smyth, and by a copy of the manuscript of C. D. Nims, lent to Professor Smyth by the late Professor A. H. Chester, of Hamilton College, Clinton, New York, and later of Rutgers College, New Brunswick, New Jersey. C. D. Nims, of Philadelphia, New York, was the chief collector of minerals from these localities for many years in the late nineteenth century, and furnished many of the specimens from northern New York which are now in museums throughout the world.

It was found that most of the old localities were either impossible


10 0 10 Miles
RIVER
LAWRENCE
Waddington
Madrid
Lisbon
Ogdensburg
Flackville
Morley
Heuvelton
CANTON
Morristown
Rensselaer Falls
Depeyster
Edwardsville
Black Lake
Pope Mills
S T L A W R
Hammond
Macomb
Richville
Bigelow
Hermon
Russell
Rossie
Natural Bridge
Gouverneur
Alexandria Bay
Edwards
Degrasse
Wegatchie
Oxbow
Fowler
Emeryville
Spragueville
Theresa
Lafargeville
Antwerp
Philadelphia
Pyrites
Oswegatchie
Harrisville
Sterlingville
Evans Mills
Perch River
F E R S O N
Great Bend
Felts Mills
Black River
Natural Bridge
Edgetown
Jordan Falls
WATERTOWN
Champion
Carthage
Indian River
Rutland Center
Deer River
Burrs Mills
Denmark

MAP 1.

to find or were so robbed of the better material that little of value from a mineralogical viewpoint could be obtained; but these, coupled with many new exposures in the Oxbow district, served to disclose the geological relations.

All of the minerals collected, excepting the micas, were determined by measuring the index of refraction by immersion in oils of known index. A set of oils was made up with indices differing by .005, and the indices of the minerals, except where stated as approximate, have been run down to a value between those of the nearest two oils. The oils were standardized frequently. When an exact determination was required, as those accompanying the analyses of a mineral, an oil was found whose index exactly matched that of the mineral, and this oil was determined directly on an Abbé Pulfrick Total Refractometer. Following E. S. Larsen,[1] the limit of accuracy of this immersion method is placed at $\pm$ .003. When an accurate determination was not made, as in some of the darker minerals or those which are considerably weathered, the index is only approximate. Even these are believed to be within $\pm$ .005 of the true value.

It has been found that a crushed mineral, such as a pyroxene, an amphibole, or a felspar, will break so as to give the highest and lowest index with little searching in each microscopic mount. A half a dozen immersions will usually suffice to give the maximum and minimum values—as shown by the magnitude of the double refraction.

Summary of the Geological History of the Region.

The rocks of this region, with the exception of small remnants of the Potsdam sandstone capping, are Pre-Cambrian.

The oldest recognizable member of the Pre-Cambrian is a sedimentary series, the Grenville, composed originally of limestones, shales, and sandstones, which have been changed to coarsely crystalline marbles, quartzites, and various schists and gneisses, by intense metamorphism.

Though these sediments must have been deposited on a previously existing floor, no remnant of it has been discerned, so that the base

[1] Larsen, E. S., "The Microscopic Determination of the Nonopaque Minerals," Bull. 679, U. S. G. S.

of the series is not known. Likewise its upper limit is nowhere to be found, as several thousand feet must have been eroded in order to expose the coarsely crystalline intrusives which outcrop at the present time. The stratigraphy of the Grenville is further masked by the ease with which the limestone members recrystallize, but there is evidence of considerable folding in the northwest area at least. All that can be said of the series at present is that it has suffered considerable distortion and is several thousand feet thick.

After the beds which form the present-day land surface had become buried under a vast accumulation of later sediments, they were subjected to metamorphism on a regional scale, and were invaded by a series of igneous intrusions. The intrusions came in in two general groups of widely different age.

The first of these groups consisted of a gabbro—now completely altered to amphibolite—followed by a red to gray, medium-grained granite-gneiss, correlated by Cushing [2] with the Laurentian granite. This rock exists as batholiths and stocks. It is partially granulated and variably gneissoid, and is accompanied by a number of acid pegmatite dikes which cut it and the surrounding rocks. It holds many inclusions of the Grenville series.

The second group of intrusives consists of the Anorthosite-Syenite-Granite-Gabbro series, which forms the main mass of the Adirondack Pre-Cambrian. The first of these, the anorthosite, so well developed in the east, does not appear in the region under discussion. The augite-syenite, with its acid border phases and quartz pegmatite dikes, followed next. This is a thoroughly gneissoid syenite with considerable variation in texture. It occasionally shows evidence of assimilation along its borders, and in some places has exerted considerable contact metamorphism where it cuts the limestone. This syenite is represented in the southern part of the region here discussed.

At a still later date, or possibly as a border or outlying intrusive facies of the syenite, a red porphyritic, biotite granite, accompanied by granite and pegmatite dikes, was intruded. These latter were

[2] Cushing, H. P., "Age of the Igneous Rocks of the Adirondack Region," *The Amer. Jour. Sci.*, January–June, 1915, 4 (39), p. 288.

accompanied by great quantities of mineralizing solutions, as shown by their containing considerable amount of tourmaline. They frequently pass out into quartz-tourmaline veins and dikes, which are associated with the greater part of the development of contact minerals in the region.

The last, like the first, of the Pre-Cambrian intrusives is a gabbro. It is the least metamorphosed of any. They have all undergone pressure of greater or less intensity and are, consequently, somewhat foliated. They are not nearly so thoroughly metamorphosed, however, as the Grenville.

These intrusions were followed by a long period of erosion, which stripped much of the overlying cover from the present-day surface. Late in Pre-Cambrian time came renewed igneous activity, which is now shown only by completely unmetamorphosed trap dikes. Any signs of surface volcanism which may formerly have existed were removed, along with the remaining cover, during the period of erosion which persisted to the end of Pre-Cambrian time and into the early Cambrian.

The later history of the region does not concern the phenomena under discussion, excepting as the Paleozoic cover prevented the further wearing down of the surface, and the Pleistocene ice cap helped to mold the present-day topography, which is nearly identical with that which was submerged under the Upper Cambrian seas. The fragmental remains of the Potsdam sandstone cap, which has not been completely removed from the region, shows that little erosion can have affected the underlying surface excepting that of the very latest period.

The surface is very rough, but the differential elevations seldom attain to more than 50 or 100 feet, and are usually considerably less. The intrusives form ridges and flat or slightly dome-topped uplands, which are heavily wooded or burned, untilled land; and the limestone lies under the cleared and cultivated valleys. Rock outcrops are everywhere exposed excepting in small areas of recent alluvium and drift, and in regions underlying the numerous swamps.

The cleared fields are full of elongated knobs and small ridges of limestone and igneous rocks. Plate VI (*A*) shows the characteristic

grazing land in the granite-limestone area in the vicinity of Oxbow in the Hammond Quadrangle. It pictures a series of ridges of pegmatite and silicated limestone, and the rough, uneven terrane. The limestone and the pegmatite are of the same gray-white color, and often can not be distinguished in the field at a distance of a few yards. Plate VI (*B*) shows a knob of impure limestone, with a well-cleared field in the middle distance, and a forest-covered ridge of intrusive rock in the background. Plate VII (*A*) shows the generally even character of the skyline, the peneplained surface of the Pre-Cambrian rocks, which, in spite of the roughness of the surface, is the most noticeable general feature of the district.

Discussion of the Metamorphism of the Region.

The region here discussed is characterized by complex metamorphic phenomena. There has been a general dynamometamorphism, followed at a later date by a series of intrusions of igneous rocks. Contact metamorphism on a regional scale, resulting from these intrusions, has been superimposed upon the older metamorphism and makes it difficult to ascribe to each its proper importance.

The coarsely crystalline character of the limestone, its similarity in regions of abundance or of apparent absence of igneous intrusions, and the very general and thorough metamorphism of the accompanying clastic sediments, demand a general alteration of the series as a whole.

It will be shown, further, that the contact metamorphism is not confined to alterations along the contacts, but is often distributed over areas at a distance from any visible contact. It is quite possible that intrusion into a series under heavy load, with the consequent increase of both temperature and pressure where heat and vertical stress already exist, would bring about a general recrystallization such as that called by Daly ("Metamorphism and its Phases," Geol. Soc. of America, Bull. 28, p. 375, 1917) "Load Contact Metamorphism"; but it would seem as though such effects should be to some extent localized, even as the development of contact minerals is localized.

The contact metamorphic effects dealt with are of three varieties.

A. Typical grazing land in the vicinity of Oxbow.

B. Cleared limestone valley and wooded ridge of granite.

First, there is the formation of completely altered bands, several inches thick and of no great lateral extent, immediately adjacent to the contact. In such cases the intrusive rock shows marked endomorphic effects. Secondly, there is the formation of irregular pockets of contact minerals at the contact or well out in the body of the limestone. These two types are connected by many intermediate gradations. Lastly, there are the fine disseminations of contact minerals over large areas of the limestone without any visible connection with an intrusive. There are also many miles of contact with little or no development of contact minerals.

Besides the phenomena described there is a border of amphibolite and garnet gneiss partly surrounding many of the intrusions of the Laurentian granite-gneiss. One of these in the Canton Quadrangle was interpreted by Martin [8] as being due to an accident of intrusion into a bed of this character, but the number of masses of Laurentian granite with such borders now known to exist in the region necessitates a causal connection. They are considered as having a contact metamorphic origin, but are not described in this paper. Attention is paid only to the scattered contact metamorphic effects of the porphyritic granite in the Hammond and adjacent quadrangles, those of a diorite at Rossie, and of the syenite in the neighborhood of Natural Bridge.

Great difficulty was experienced in gathering any exact quantitative data because of the scattered nature of the contacts. There are no halos of diminishing metamorphism, no outer and inner zones to furnish samples at definite distances from the intrusive and to show time relations, etc., as so often described in cases of contact metamorphic ore deposits of later geological date. Instead of this, the whole area is underlain at no great depth by intrusive rocks. These project through the limestone in a variety of forms, and cut it into long belts and irregular isolated patches. At a distance of one hundred yards from any one contact it is usually impossible to say what particular exposure of granite or pegmatite may have affected the limestone. Further to the southeast, in the higher land, erosion

[8] Martin, J. C., "The Pre-Cambrian Rocks of the Canton Quadrangle," New York State Mus. Bull. No. 185, Albany, 1916.

has stripped off the sedimentary cover and the igneous rocks are everywhere exposed. In the area under discussion, it must always be borne in mind that an igneous rock is very likely nearer to the observer in a vertical than in a horizontal direction.

The problem then resolves itself into a matter of linking a particular set of metamorphic phenomena to a certain type of intrusive or series of intrusives; to an accurate description of the various local developments of metamorphic minerals; and to the presenting of evidence bearing upon the question of recrystallization and the addition of foreign material.

Contact metamorphism is here taken to mean all those changes produced in the limestone country rock resulting from the intrusion of igneous masses, whether by simple recrystallization or by the addition of magmatic substances, or both, together with accompanying changes in the igneous rocks themselves.

It is generally recognized now that the contact metamorphism of a limestone involves not only a rearrangement of the materials already present in the rock with the formation of new minerals, particularly silicates rich in lime and magnesia, and with the elimination of carbon dioxide, but also an addition of material from the magma, and consequent further formation of new minerals. It is only rarely that the relative importance of these two sources of new minerals can be quantitatively stated, but the present tendency is toward assigning a greater rôle to the addition of magmatic material and to reactions between the intrusive and the country rock.

It is recognized that the materials in an igneous rock represent only a part of the components entering into the composition of the magma from which the rock is formed. Active volcanoes, fumaroles, and lava streams prove the presence of immense quantities of steam and gases in a magma. The volatile constituents, water, silicon, chlorine, fluorine, phosphorus, sulphur, etc., will escape as the magma approaches the surface, and the pressure becomes less.

In an area such as this, underlain by intrusives and intersected by numberless dikes, sills, and veins of pegmatite, and dikes and veins of quartz, containing tourmaline, chondrodite, apatite, and some fluorite, there is evidence of sufficient available magmatic material to

account for all the contact phenomena. The limestone, where not impregnated with obviously pneumatolytic minerals, is a dense, crystalline marble with interlocking grains of calcite, a variable percentage of magnesia, and very rare scattered crystals of phlogopite, diopside, and tremolite, besides flakes of graphite. The mineralized areas follow no bands, such as to suggest an originally impure limestone, but occur in irregular fashion. Thus the limestone appears to have lacked the impurities necessary to produce the existing silicate aggregates by mere heat together with the original moisture content of the rock; and the formation of contact minerals must, therefore, have been due to additions from the magma.

Lindgren ("Mineral Deposits," p. 713) says: "The hot intrusive, whether molten or just consolidated, and the adjacent cooler limestone, form a system in which, by means of gases, there will usually take place a vigorous exchange of material. Most of the exchange will take place at the cooler side, but the intrusive will also receive material, perhaps mainly carbon dioxide and oxides of calcium and magnesium, from the sediments." Such endomorphic effects are very common in this region, and occasionally occur to the practical exclusion of exomorphism.

The depth of formation of the contact minerals is hard to determine. Lindgren (*op. cit.*, p. 723) concludes that many contact metamorphic deposits are formed at less than 3,000 feet below the surface. Actual figures can not be given in this case; but the lack of any fine-grained border to the intrusives, even where no minerals are formed at the contact, suggests a heated condition of the limestone and consequent depth. It is shown, further on, that the absence of a contact zone along much of the border may be due in part to the lack of openings to afford a release of pressure and escape for the magmatic vapors which would also imply considerable depth.

At the height of contact metamorphism, the true contact silicates, such as diopside and tremolite, together with spinel were formed. These conditions gradually lessened in intensity until serpentine, talc, and chlorite were formed at the expense of the earlier silicates. As evidence is presented to show that the contact silicates were formed through a rather wide range of conditions extending into the hydro-

thermal stage, it must have been near the end of this later stage before the same silicates became unstable and gave way to the alteration products.

Necessarily these conditions overlapped from place to place. They are not measures of time, but, rather, of changing conditions, of which time is only one factor.

The temperature of the formation of the minerals of the various contacts is impossible to state accurately. There seems, however, to have been some difference in the prevailing temperatures of the syenite and the granite contacts. Amphibole is found in the granite contacts almost as plentifully as pyroxene. It is generally regarded as formed at lower temperatures than pyroxene and in the presence of more aqueous vapors. None of the syenite contacts yielded any amphibole. Wollastonite occurs quite frequently in the syenite area, but is not found in any of the granite contact masses. According to Eskola,[4] where wollastonite is present the temperature during metamorphism has exceeded a certain limit which varies with pressure. At atmospheric pressure it is about 500° C., and increases to about 950° C. at 15,000 atmospheres. As quartz and calcite, in association, are more common than wollastonite, the conclusion might be drawn that the metamorphism had occurred at temperatures generally below that of the quartz-calcite curve for the particular pressure involved.

Eskola adds that it may be said that quartz has been added by hydrothermal processes later than the strongest metamorphism. This is true to a great extent in the granite area, but even there a great deal of quartz exists in the pegmatite dikes in direct contact with limestone. These dikes were connected with the greatest metamorphism, but in many cases there is no development of metamorphic minerals, and in other places only calcium-magnesium silicates or quartz-tourmaline and recrystallized calcite. In the syenite region there is little or no quartz of a later generation than the mass of the metamorphism, and only the occasional development of wollastonite shows the variable temperature as well as composition of the magmatic vapors. Wollastonite does not occur singly, but always in con-

[4] Eskola, P., "On the Petrology of the Orijarvi Region in Southwestern Finland," Bull. de la Commission Geologique de Finlande, Avril, 1914, p. 160.

nection with a calcium-magnesium silicate. While the formation of wollastonite or quartz-calcite depends upon temperature and pressure, the formation of the calcium magnesium or the pure calcium silicate depends upon the composition. After the available magnesia has been used up in the formation of diopside, wollastonite will form, provided the temperature is still high enough; if it has fallen below the quartz-calcite curve at that pressure, quartz and calcite will crystallize out.

The available magnesia, outside of some which is introduced by the magma, is probably controlled more by the amount which the magmatic solutions are capable of absorbing during their passage through the limestone than by diffusion of magnesia toward the crystallizing material through the solid rock. N. L. Bowen [8] speaks of the limited radius through which diffusion can act freely even in a magma. Of course, in the present case, the time through which diffusion may act is not limited by the sinking of crystals, and the tendency shown in the partial analyses of the limestone, given further along (namely, to have a lower per cent. of magnesia in the calcite taken from among calcium-magnesium silicates than in that taken from more or less pure limestone), though far from conclusive, suggests that diffusion has taken place. In a like manner the presence of magnesia left over suggests a limit to the amount which can be taken up in this way. On the other hand, the passage of the vapors through long, narrow channels gives them a perfect opportunity to absorb considerable quantities of magnesia and other materials.

Description of Localities in the Oxbow District.

The best order in which to consider the minerals of this region might seem to be: (1) those which can be easily proved to be of contact origin because of their position with reference to intrusive contacts; and (2) those whose origin, as far as field evidence goes, is more obscure. But owing to the fact that the phenomena studied relate to three types of intrusives, it is thought best to describe each one as a whole. Furthermore, because the field evidence in the district about Oxbow in the Hammond Quadrangle, where the limestone

[8] Bowen, N. L., "The Later Stages of the Evolution of the Igneous Rocks," Supplement to the *Jour. of Geol.*, November–December, 1915, pp. 11–12.

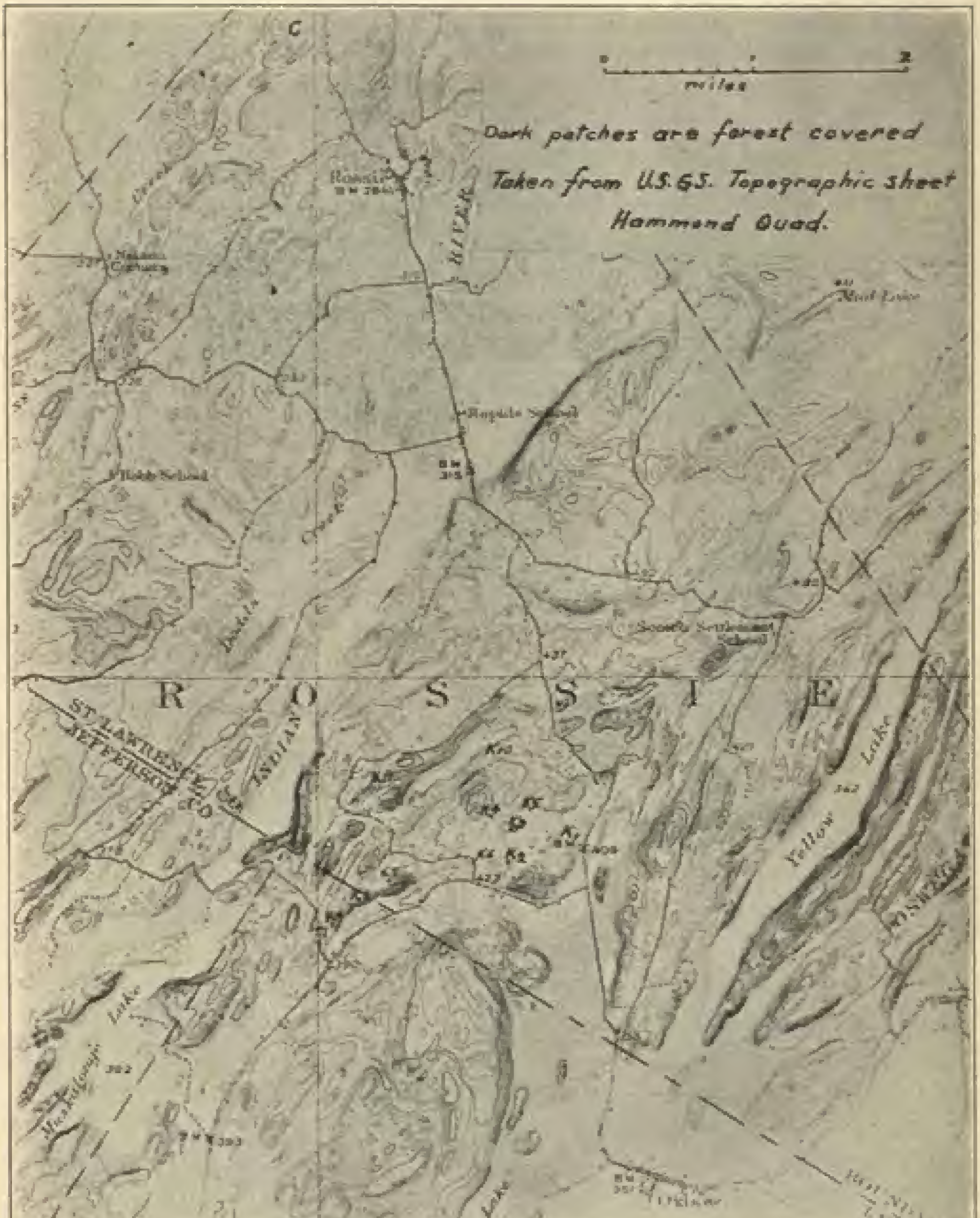
is intersected by the porphyritic granite gneiss, some granite dikes, and a large number of pegmatite dikes, is such as not only to show the relation in space of the zones of greater and less mineralization to the intrusive, but also to tie the mineralization far from the contact, the quartz-tourmaline veins, the pegmatite, and the granite dikes definitely to the intrusive, this district is taken first. Following this, the other districts connected with granitic intrusions are described, and finally the districts marked by the existence of the more basic intrusives. Any reader wishing more precise directions for locating the following mineral occurrences than are given here is referred to the writer's article, "The Minerals of St. Laurence, Jefferson, and Lewis Counties, New York," in the *Journal of the Mineralogical Society of America,* Vol. 6, Nos. 10 and 11, for October and November, 1921.

The Oxbow District.

The most interesting of the localities studied, both from the point of view of the variety and number of the minerals developed, and from that of the geological associations, lies in the south-central portion of the Hammond Quadrangle (see Map 2). About four miles north of the village of Oxbow, roughly paralleling the creek which runs slightly north of west, south of the road between Scotch Settlement School and Rapids School, lies the southern extremity of an intrusive mass of coarse, porphyritic granite. The exposure of the granite runs off to the northeast, while south of it lies an area of limestone intersected by many dikes which have their origin in this granite mass, and which have given rise to extensive mineralization.

This mineral region, which will be called the Oxbow district, forms a roughly oblong patch south of the granite boundary, east of the Indian River, and west of a line through Payne's Lake and Yellow Lake. Its southern limit is about at the zigzag east-west road one half mile south of the county line.

The granite itself is a coarse, roughly gneissoid, porphyritic rock. Thin sections show it to be composed of strained and granulated quartz, variable amounts of microcline, microperthite, oligoclase, and probably some orthoclase; hornblende, and biotite, with apatite, titanite, and magnetite forming common accessories, tourmaline a rare accessory, and zircon a very rare one.


miles
Dark patches are forest covered
Taken from U.S.G.S. Topographic sheet
Hammond Quad.
RIVER
Creek
R O S S I E
ST. LAWRENCE CO.
JEFFERSON CO.
INDIAN
Yellow Lake
Lake
Scotts Settlement School
Rapids School

Map 2.

The biotite in the granite and granite dikes is partially altered to chlorite, while the hornblende and, where present in the dikes, pyroxene have undergone an alteration to serpentine along with the generation of calcite and hematite.

The northern part of the area under discussion, just south of the granite boundary, contains numerous dikes of granite. These are, as a rule, slightly more acid than the main mass of the rock and are composed chiefly of microcline and granulated quartz, with small amounts of hornblende and mica drawn out into stringers, with titanite and occasionally tourmaline as accessories. They are everywhere accompanied by a certain number of pegmatite dikes.

Southward the zone of dominant granite dikes passes into another one of mixed granite and coarse quartz-felspar pegmatite dikes and sills and, still farther south, the latter occur to the complete exclusion of the granite. Some of the large masses show a good transition between the granite and the pegmatite. One in particular shows a fine-grained tourmaline-bearing granite sill about 100 yards long, grading at several points into a coarse quartz-felspar aggregate similar to the pegmatite dikes and sills.

South of here the pegmatites continue to be very plentiful and, about half way down the area, mineralized zones are found. These increase in number until the southern part is reached and the pegmatite intrusives thin out. Throughout the mineralized zone, pockets and disseminations of minerals are found in otherwise clear limestone at a distance from the intrusives as well as along the borders and in the intrusives themselves. Not infrequently the minerals are found beyond the exposed end of a sill or dike of pegmatite, or connected with a quartz vein parallel to, or at the end of, such a pegmatite.

So from north to south within the Oxbow district we find granite, then limestone cut by predominating granite dikes, then mixed granite and pegmatite dikes, large quantities of pegmatites with some mineralization, large quantities of pegmatites with maximum mineralization, and finally a dying out of the pegmatites with a considerable mineralization. West of the southern part of this area there are large bosses of porphyritic granite, and south of it another mass of the same rock with its accompanying dikes and sills, and, in the cen-

tral part of the area, there is a granite sill several hundred yards long and fifty yards or more wide; still the relations outlined above are clear enough when taken as a whole.

A line followed across the center of the area, in a direction a little north of west and south of east, reveals the following relations. Just west of the Oxbow-Scotch Settlement School road there is a region of limestone which contains linearly arranged nodules and small scattered crystals of minerals, prominent among which are wernerite, chondrodite, and spinel, with brown tourmaline present, though rare. There are no signs of intrusives at this place; but one quarter of a mile to the west the level of this region descends abruptly to that of the marsh, about 80 feet below. At the base of this cliff several small dikes are exposed. West across the marsh there are no exposures. Beyond the marsh the level rises again, and for some 600 feet there are only two exposed pegmatite knobs. These increase greatly toward the west, till about half way across the area a large mass of granite is encountered. There is a little mineralization here, but the greatest amount lies to the south in line with the most marked development of dikes.

Beyond the granite, to the west, the limestone is again dissected by numberless pegmatite masses, and is frequently intricately intergrown by veins of quartz along with a little felspar. Tourmaline is very rarely seen in this last area, and the calcium-magnesium silicates are nearly totally lacking.

So from east to west we find disseminated minerals with pegmatites at a lower elevation immediately alongside (see Fig. 4), a covered area followed by one with a few pegmatites, then an increasing number of pegmatites with some mineralization, then granite, and finally pegmatites and limestone replaced by quartz, with little tourmaline and very few lime-magnesia silicates. A discussion of these relations will be reserved until after a description of the individual localities in this zone has been given.

Reference to the accompanying map (No. 2) will show the location of the different occurrences described below. They are everywhere referred to by numbers, which correspond to those on the map as well as to the labeled specimens from every locality.

69–K–1. On the east bank of the bed of the brook there is a dark, greenish-black rock which looks like an intrusive sill of basic composition. At its down-slope edge there is a considerable development of silicates. The rock itself is about 30 feet thick and has apparent intrusive relations, but, according to the evidence of the microscope, is nothing but a completely altered bed of limestone. It is composed mainly of light green diopside and phlogopite, with tremolite and apatite as accessories. Next to it there is a less altered rock containing only diopside and calcite. The diopside has grown out into the calcite and occasionally includes bits of quartz and phlogopite.

Spread irregularly along this contact are crystals of green diopside, deep brown hornblende, white marialite, and bronze phlogopite. There are many projecting knobs of pegmatite on the slope above this zone, and the limestone is more or less full of mica and tremolite, besides the quartz and felspar of the pegmatites.

The minerals:

Diopside...... $\left.\begin{array}{l}\alpha = 1.673 \pm .003\\ \gamma = 1.700 \pm .003\end{array}\right\}\gamma - \alpha = .027$, $Z \wedge c = 39°$.

Hornblende... $\left.\begin{array}{l}\alpha = 1.636 \pm .003\\ \gamma = 1.657 \pm .003\end{array}\right\}\gamma - \alpha = .021$, $Z \wedge c = 21°$.

Phlogopite.... $\left.\begin{array}{l}\gamma = 1.588 \pm .003\\ \alpha = 1.547 \pm .005\end{array}\right\}\gamma - \alpha = .041$.

Marialite..... $\left.\begin{array}{l}\omega = 1.555 \pm .003\\ \epsilon = 1.541 \pm .003\end{array}\right\}\omega - \epsilon = .014$.

Apatite.......blue green, uniaxial, low biref.

Tremolite.....$\alpha = 1.605 \pm .005$. Biref. high. $Z \wedge c = 19°$. White, fibrous, good prismatic cleavage.

69–K–1–h. A few hundred yards south along the slope of the hill a large-sized dike of pegmatite intersects a fairly pure limestone. A few inches from the dike it contains tremolite, diopside, chondrodite, and phlogopite. These are microscopic, with the exception of chondrodite and phlogopite. The latter is colorless from hydration and has lost its flexibility. Its indices of refraction are very low. $\gamma = 1.555 \pm .003$. The indices of the chondodrite are as follows: $\alpha = 1.600 \pm .003$; $\gamma = 1.627 \pm .003$; $\gamma - \alpha = .027$. Pleochroism; white to yellow.

The pegmatite dike is an aggregate of quartz and felspar. The

A. Surface of Pre-Cambrian peneplain, looking northwest from granite ridge west of Oxbow.

B. Lower contact of pegmatite dike cutting limestone. Chisel on contact. 69-K-2-a. See p. 20.

latter comprises microperthite, with a little microcline and very rare albite. The microcline shows its characteristic gridiron-twinning structure. $\gamma = 1.531$ and $\alpha = 1.521$. Albite gives $\alpha < 1.531 < \gamma$. Some untwinned fragments may be orthoclase.

69–K–2–a. At this point a knob of pegmatite projects out a few feet from the north side of a small valley. It does not appear on the hill above. The lower few feet of the dike show a marked concentration of green diopside with some brown tourmaline and pyrrhotite, now limonite. Interlaced fibers of tremolite and phlogopite, one to two inches long, lie at right angles to the contact over most of its lower extent (Plate VII (*B*)). This is surrounded by a greenish-white, massive diopside rock, containing pockets of blue-green apatite crystals, hydrated, white, octagonal crystals of diopside, and phlogopite. The apatite is intergrown with the other minerals, but also occurs as inclusions in them.

The upper contact is marked by only a very little tremolite and apatite. The limestone alongside of this knob of pegmatite shows concentrations of phlogopite and chondrodite.

The minerals:

Tremolite..... $\left.\begin{matrix}\alpha = 1.600 \pm .003 \\ \gamma = 1.627 \pm .003\end{matrix}\right\} \gamma - \alpha = .027,\ Z \wedge c = 21°.$

Phlogopite....pale bronze to white, hydrated. Indices very low. $\gamma = 1.565$ and lower.

Chondrodite.. pale yellow brown.

Apatite....... $\left.\begin{matrix}\omega = 1.634 \pm .003 \\ \epsilon = 1.631 \pm .003\end{matrix}\right\}$ Uniaxial (—).

Diopside..... white opaque, eight-sided crystals. Indices lowered by hydration.

$\alpha = 1.606 \pm .005.$

$\gamma = 1.625 \pm .005.$

green-white, massive diopside.

$\left.\begin{matrix}\alpha = 1.664 \pm .003 \\ \gamma = 1.694 \pm .003\end{matrix}\right\} \gamma - \alpha = .030,\ Z \wedge c = 37°.$

69–K–2–b. Two hundred feet north up this valley a ten-foot-thick east-west pegmatite dike cuts the limestone under two maple trees. The dike is a crystalline aggregate of quartz-felspar and minor diopside. The felspar is mostly microperthite with grains of orthoclase whose indices are $\alpha = 1.520 \pm .003$ and $\gamma = 1.525 \pm .003$, and albite with $\alpha = 1.530 \pm .003$ and $\gamma = 1.539 \pm .003$.

Alongside of the dike there are pockets of phlogopite five inches in cross-section, and apatite in hexagonal prisms one inch thick. Large hydrated diopsides occasionally accompany these. None of these minerals occur immediately along the contact, but are from one to three feet from it.

The minerals:

Phlogopite....fresh, bronze.

Pyroxene.....hydrated, white, earthy looking crystals as much as three inches long. They are too badly weathered to determine the indices. Probably diopside.

Apatite.......greenish-blue crystals and massive material. Some of the crystals are contained as inclusions, both in the pyroxene and the phlogopite. Others are intergrown with the other minerals.

69–K–2–d. About one hundred yards east from K–2–a there is a pegmatite dike projecting above ground for a distance of forty feet along a slope. This pegmatite contains considerable quantities of black tourmaline and titanite, with a concentration of green hornblende near its lower contact. The contact effects are purely endomorphic, as the limestone shows only a concentration of graphite bands parallel to the contact.

The minerals:

Quartz.

Felspar.......Orthoclase. $\left.\begin{array}{l}\alpha = 1.519 \pm .003\\ \gamma = 1.525 \pm .003\end{array}\right\}\gamma - \alpha = .006.$

Microcline. $\left.\begin{array}{l}\alpha = 1.525 \pm .003\\ \gamma = 1.530 \pm .003\end{array}\right\}\gamma - \alpha = .005.$

Titanite...... well-developed wedge-shaped crystals.

Hornblende... $\left.\begin{array}{l}\alpha = 1.627 \pm .003\\ \gamma = 1.650 \pm .003\end{array}\right\}\gamma - \alpha = .023,\ Z\wedge c = 17°.$

69–K–3. This is a zone several hundred yards N. 28° E. from K–2–b, where the limestone is extensively intersected by pegmatite dikes, and silicates are disseminated in the limstone as well as along the contact. The pegmatites project through as nearly circular knobs and dikes as much as 100 feet long. They contain inclusions of the limestone and have caused local folding. This area now contains boulders of phlogopite, calcite, and chondrodite.

69–K–3–a. A few yards northeast of K–3 there is a pegmatite knob containing considerable brown tourmaline. The contact is entirely barren except for a very small concentration of green pyroxene at one spot in the dike and a knot of the same material in the limestone two inches from the contact.

Another dike in the same zone shows a concentration of brown tourmaline intergrown with silky, elongated prisms of tremolite. The limestone contact is covered, but cobbles of phlogopite with six-inch quartz crystals suggest that the action on the limestone was confined to the development of those minerals.

There are many absolutely barren contacts in this region. Others abound in which a concentration of graphite, in both the intrusive and the limestone, appears to be the only consequence of intrusion.

A slide cut from limestone near the contact with a dike in which macroscopic quartz is visible shows the beginning of the replacement of limestone by quartz and felspar. Plate IX (*A*).

The lower contact of one dike shows a concentration of diopside, and the limestone under it contains considerable diopside, a very little apatite, irregularly oriented flakes of graphite, and later quartz and felspar.

A knob of limestone isolated from any dikes contains small, silky crystals of tremolite, lilac to red spinel, serpentine, and chondrodite. An irregular development of phlogopite and wernerite in the limestone ends the minerals from this locality.

The minerals:

Missonite..... $\left.\begin{array}{l}\omega = 1.563 \pm .003 \\ \epsilon = 1.547 \pm .003\end{array}\right\} \omega - \epsilon = .016.$

Phlogopite....mostly hydrated. $\gamma = 1.574.$

Spinel........clear lilac to reddish. $\eta = 1.710.$

Tourmaline...brown. $\left.\begin{array}{l}\omega = 1.640 \pm .003 \\ \epsilon = 1.620 \pm .003\end{array}\right\} \omega - \epsilon = .020$

Tremolite.....white, silky crystals.

$\left.\begin{array}{l}\alpha = 1.600 \pm .003 \\ \gamma = 1.625 \pm .003\end{array}\right\} \gamma - \alpha = .025.$

69–K–5. To the northeast of K–3–a there is much less mineralization of the limestone, in spite of the large number of the pegmatite dikes which carry considerable brown tourmaline. The tourmaline

has crystallized in the edge of the dikes, and very rarely passes out into the limestone. At one locality there is an old pit which was opened in the limestone. A good many quartz veins pass out into the limestone, which becomes nearly a solid mass of diopside and apatite, with considerable calcite, graphite, and granular pyrrhotite. This latter is very local, but occurs abundantly as grains and small crystals. There is some quartz which has replaced the limestone at a later date than that of the formation of the diopside, tourmaline, and apatite.

The minerals:

Apatite.......light blue green.

$$\left.\begin{array}{l}\omega = 1.634 \pm .003 \\ \epsilon = 1.631 \pm .003\end{array}\right\}\omega - \epsilon = .003.$$

Diopside......deep green, vitreous.

$$\left.\begin{array}{l}\alpha = 1.670 \pm .003 \\ \gamma = 1.699 \pm .003\end{array}\right\}\gamma - \alpha = .029.$$

Tourmaline...brown.

$$\left.\begin{array}{l}\omega = 1.638 \pm .003 \\ \epsilon = 1.620 \pm .003\end{array}\right\}\omega - \epsilon = .018.$$

Felspar.......Albite. $\alpha = 1.530 \pm .003.$
$\gamma = 1.541 \pm .003.$

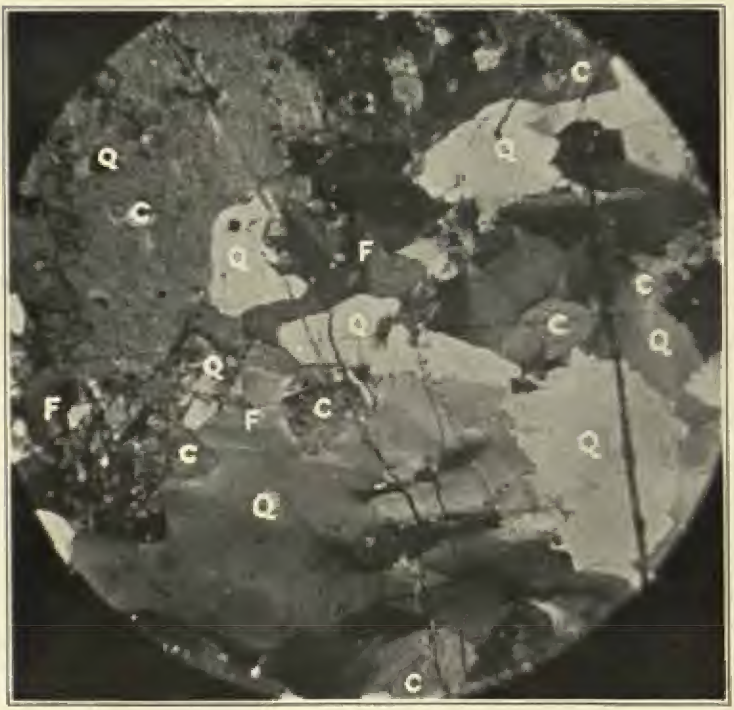
Microcline. $\gamma = 1.530 \pm .003$—gridiron str.

The apatite is apparently of the same age as the other minerals in this locality, and the titanite is found in the limestone away from the contact, though always near pyroxene, if not in it.

The next four localities lie in a line bearing southwest from, and starting a few hundred yards west of, K–2.

69–K–6. The road has cut through the contact between a pegmatite dike and the limestone. The intrusion shows a concentration of diopside and a little apatite and titanite. Only the diopside passes out into the limestone, and that to a very slight extent. The limestone contact is marked by nothing more than the development of phlogopite and, in one place, by a 6-inch thick aggregate of massive, green-gray wernerite and crystalline phlogopite.

Dikes and knobs of pegmatite are so numerous in this region as to form fully fifty per cent. of the exposed surface rock. The limestone is white, finely granular, and contains knots of phlogopite in a few rather restricted areas, and considerable amounts of chondrodite over a wide zone. Plate IX (*B*) shows a microphotograph of a slide



A. Quartz and felspar replacing calcite. They are both strained and granulated and cut by veinlets of later calcite. Q = quartz. F = felspar. C = calcite-veinlets and calcite. (Crossed Nicols, × 20 diams.)

of a part of a chondrodite zone which occurs as a band paralleling the tip of three or four pegmatite knobs. This rock is composed of calcite of two generations, chondrodite, phlogopite, diopside, graphite, rare apatite, and quartz, which was the last to form.

One lens of limestone, which runs into a crack between two branches of a dike, is completely changed into a massive scapolite-mica aggregate. Plate VI (*A*) shows the character of the topography in this region.

The minerals:

Scapolite .....(1) from road cut.
Marialite; brownish white, massive.
$$\left.\begin{matrix}\omega = 1.561 \pm .003\\ \epsilon = 1.543 \pm .003\end{matrix}\right\} \omega - \epsilon = .018.$$
(2) from lens in the dike.
Missonite; brown, massive.
$$\left.\begin{matrix}\omega = 1.563 \pm .003\\ \epsilon = 1.546 \pm .003\end{matrix}\right\} \omega - \epsilon = .017.$$
Tourmaline ... black. Only one speck seen in dike.

Diopside .....gray-green to rich green.
$$\left.\begin{matrix}\alpha = 1.671 \pm .005\\ \gamma = 1.700 \pm .003\end{matrix}\right\} \gamma - \alpha = .029,\ Z \wedge c = 39^\circ.$$
Felspar ......Microperthite.
Microcline—gridiron structure.
Albite. $\alpha = 1.530 \pm .003.$
$\gamma = 1.540 \pm .003.$

69–K–7–a. This locality is at the south end of a large pegmatite dike which forms a wooded ridge. Disseminated chondrodite, massive diopside, some tremolite, and loose boulders of phlogopite are found along the edges of this dike at the base of the cliff. Beyond the end of the dike another small knob of pegmatite rises up above the limestone surface, and thirty feet beyond that there is a pocket of chondrodite with large-sized purple spinels. Fig. 1 *A* gives a rough idea of the relations. Tourmaline is very scarce in these dikes.

The minerals:

Chondrodite ..$\left.\begin{matrix}\alpha = 1.607 \pm .003\\ \gamma = 1.636 \pm .003\end{matrix}\right\} \gamma - \alpha = .029.$

Spinel ....$\eta = 1.713 \pm .003.$ Apparently another spinel in the section with index too high to determine. Probably an iron spinel.

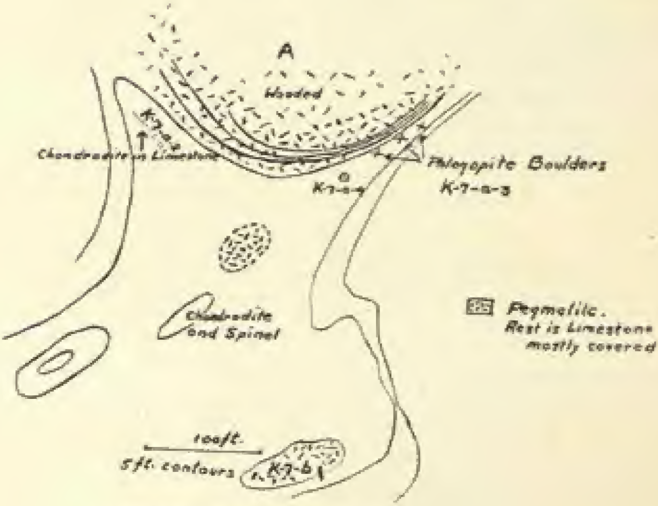
Diopside .....(at K-7-a-2) massive gray material.

$$\left.\begin{aligned}\alpha &= 1.664 \pm .005\\ \gamma &= 1.698 \pm .005\end{aligned}\right\}\ \gamma - \alpha = .034,\ Z \wedge c = 42^\circ.$$

Tremolite ....(at K-7-a-2) white silky fibers in limestone.

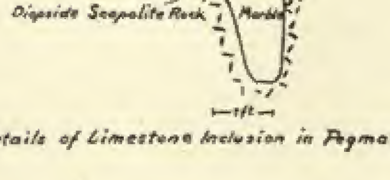
$$\left.\begin{aligned}\alpha &= 1.606 \pm .003\\ \gamma &= 1.636 \pm .003\end{aligned}\right\}\ \gamma - \alpha = .030.$$

A



Plan of Mineralized Zone K-7

B



Details of Limestone Inclusion in Pegmatite at K-7-b

69–K–7–b. At K–7,-b shown in the sketch there is an irregular pegmatite cutting through the limestone, and a good example of limestone filling a depression in the pegmatite and simulating a dike. Plate X (*B*) shows the peculiar relations. Fig. 1 *B* gives the details.

A good deal of the limestone next to the pegmatite is unchanged, but on the upper surface and near the top of the "dike" it is completely altered to a massive, finely crystalline aggregate of diopside and scapolite, containing a few small anhedral apatite crystals. The three are of contemporaneous origin.

The marble next to this alteration product is very nearly pure. It contains only a little phlogopite and quartz, which together make up about one per cent. of the rock. The contact between the pure limestone and the completely altered silicate rock is very sharp. The quartz has replaced the calcite. It is strained and granulated, and has been in turn replaced by calcite and differently oriented quartz along its borders. Both the quartz and calcite replace phlogopite.

The minerals:

Scapolite .....Meionite. $\left.\begin{array}{l}\omega = 1.590 \pm .003 \\ \epsilon = 1.555 \pm .005\end{array}\right\} \omega - \epsilon = .034.$

Diopside .....Violet tinted to brown.

$\alpha = 1.669 \pm .005.$	$\gamma - \alpha = .029.$
$\gamma = 1.698 \pm .005.$	$Z \wedge c = 39°.$

69–K–8. The chondrodite continues in patches southwest along the same ridge, but disappears before reaching K–8. At K–8 it comes in again parallel to a contact zone which is several feet away from it. This is a well-developed pocket, four to five feet wide and several feet long, composed of diopside, hornblende, phlogopite, and brown tourmaline, alongside of a dike holding black tourmaline. Next to the dike the contact rock is fine-grained and whitish. Away from the dike, it passes into a darker, coarser, massive, diopside and mica rock, and finally into an aggregate of coarse calcite, phlogopite, and tourmaline. The chondrodite zone follows along outside of this, and one hundred feet farther south it ends in a pocket of pink spinel.

The minerals:

Hornblende .....as crystals and in groundmass.

$\alpha = 1.624 \pm .003.$	$\gamma - \alpha = .014.$
$\gamma = 1.638 \pm .003.$	$Z \wedge c = 21°.$

Diopside ....square octagonal crystals in cavities, and as a white groundmass. Badly weathered and opaque.
Felspar of dike. . Microcline, gridiron structure.
Andesine. $\alpha = 1.546 \pm .003.$
$\gamma = 1.553 \pm .003.$

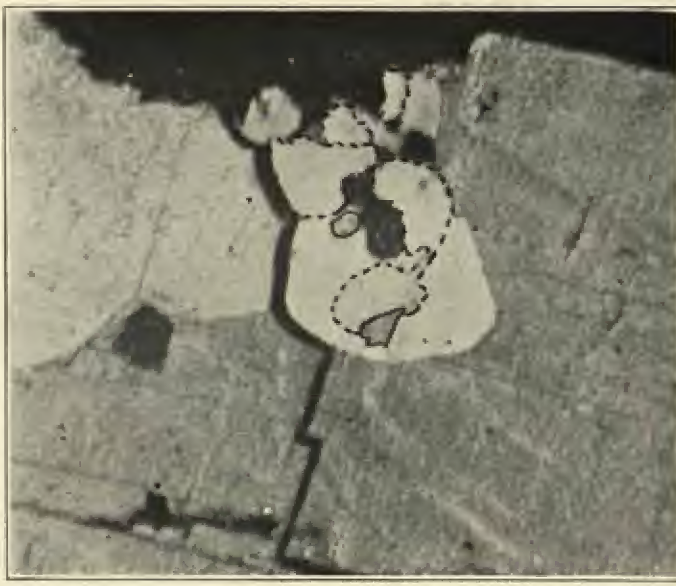
69–K–9. One hundred yards farther south, at the northeast pointing V in the road, there is a good development of violet spinel in serpentine. In thin section the serpentine is shown replacing chondrodite. It does not replace the calcite, as is shown by the fact that it never occurs in the calcite at any distance from residuals of chondrodite, but remains grouped about them and retains the cleavage of the chondrodite. See Plate IX (*B*). Phlogopite and a little calcite make up the rest of this rock. The limestone of this region is full of quartz, and in places is almost completely replaced by quartz and some felspar. A gabbro alongside of K–9 is also full of acid material. Plate VIII (*A*) shows this quartz and felspar in limestone. The quartz is strained and granulated, and both it and the felspar have been replaced to some extent by later calcite.

69–K–10. At this point, in the north-central part of the region, there is a sill of granite of considerable extent projecting through the limestone. Along its edge at K–10, both it and the limestone are cut by a number of tourmaline-bearing quartz veins. One small branching vein winds along in view for about 200 feet. The limestone on both contacts along nearly the whole of its length is filled with crystals of deep green, silky, pargasite. The vein carries considerable tourmaline, and occasionally spreads out and covers the limestone with a mesh of quartz. There is a marked development of graphite accompanying some of these veins of quartz.

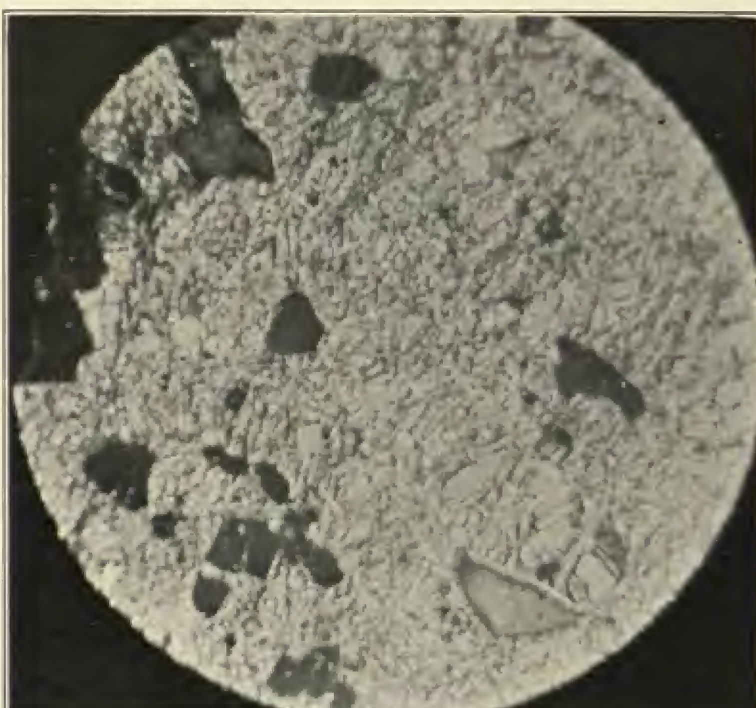
The minerals:

Pargasite.......... $\alpha = 1.617 \pm .003.$ $\gamma - \alpha = .022.$
$\gamma = 1.639 \pm .003.$ $Z \wedge c = 22°.$

69–K–11. Across the swamp, on the ridges to the west of K–10, there is a very marked lack of the minerals characteristic of the zone just described. Pegmatite dikes occur in abundance, quartz veins cut these, and the limestone is often full of a reticulated network of quartz which weathers into ridges with rough, irregular surfaces, standing up above the rest of the limestone. See Plate X (*A*).



A. 69-K-3-c-1. Quartz and felspar replacing limestone. Dotted lines surround quartz. Solid lines surround calcite. Rest of light-colored material is plagioclase. Dark groundmass is calcite. (Crossed Nicols, $\times 30$ diams.)



B. Serpentine replacing chondrodite. Light remnants are chondrodite. Dark triangle is calcite. Black patches are spinel. (Crossed Nicols, $\times 20$ diams. See p. 25.)

Two slides from the pure limestone of this region show the presence of a little strained and granulated quartz, microcline, and sodic plagioclase, rare rounded crystals of diopside, and flakes of graphite. One of these specimens is from a dark gray limestone which breaks up into a sooty powder (K–11–b). This contains a considerable quantity of graphite, both in the calcite, quartz, and diopside.

North from here, along the strike, the same conditions prevail. Quartz stringers everywhere intersect the limestone, and occasionally a little tourmaline is present in the quartz; but, excepting the very rare quartz, felspar, and diopside in the body of the limestone, and several small zones of chondrodite, there is no mineralization.

Summary of the Relations in the Oxbow Region.

The most noticeable fact which is brought to one's attention by field work in this region is that of the many miles of barren contact, where not even a recrystallization of the limestone marks the sharp boundary between the intrusive and intruded rock. Other miles are marked by a discontinuous zone of coccolite, varying in width from one quarter to one eighth of an inch; while last of all, and forming but a negligible part of the whole, we find the pockets of silicates and an occasional altered zone a few feet in length.

Perhaps just as remarkable is the occurrence of similar pockets and nodules of silicates at a distance from any contact, and the widespread distribution of minerals throughout a "clean" white crystalline limestone.

The limestone is very generally a coarsely crystalline white marble, with an average magnesia content far too low to be called a dolomite. The intrusions vary from porphyritic granite to pegmatite dikes bearing tourmaline and followed by quartz-tourmaline veins. Quartz with a little felspar also works its way out into the limestone, forming a rough-surfaced, siliceous marble.

Granite-limestone contacts are barren unless quartz veins or pegmatites, or both, are present. Pegmatite contacts are more productive, and the limestone about them contains scattered silicates. The possibility of both of these increases with the presence of tourmaline. Quartz dikes, as the last representative of pegmatitic action, especially

when they bear tourmaline, are very likely to be accompanied by pockets of metamorphic silicates; though, when the quartz is disseminated throughout the limestone, it is rarely accompanied by any contact minerals.

The result of the distribution of the intrusives, as outlined in the beginning of this chapter, is the collection of most of the contact metamorphic phenomena near the center of the area where the dikes are thickest. The minerals are even better developed to the south where the dikes begin to thin out, but there is no certainty that the effect of other porphyritic granite masses to the south and west is not felt in that region. The phenomena of the eastern part of the east-west line, where scattered minerals appear on the surface of an elevated ridge, while at its base pegmatite dikes barely reach through the limestone, suggests that the sequence granite—granite dikes—granite and pegmatite dikes—large numbers of pegmatite dikes with contact silicates, is a vertical as well as a horizontal one. The surface occurrence of various members of this sequence is probably controlled more generally by the upper surface of the underlying granite than by the subaërial topograph, though this latter occasionally influences the presence or absence of minerals. See Fig. 2.

Illustrating Relations of Intrusives to Mineralized zone at East edge of Oxbow Area.

There are a few general relations among the minerals which can be noted here, as they will help the reader to compare the localities subsequently described.

Titanite occurs as a minor accessory in the granite, but it is rare as a contact mineral. When it does occur, it is usually in an endo-

morphic development of the intrusive. This has only one known exception; *i.e.,* at K–5–b.

Apatite is plentiful as an accessory in the granite. In this case it is euhedral. It occurs very abundantly, as both an endomorphic and an exomorphic constituent of many of the contacts, but is never found at a greater distance than a few feet from the intrusive.

Diopside-tremolite-scapolite-phlogopite; these four minerals are the common contact silicates of the area. They occur immediately on the contact and at any distance from it. They are both endomorphic and exomorphic. Diopside is the commonest. It, together with scapolite and phlogopite, completely replaces the marble along a number of the contacts. Diopside also forms the larger part of the endomorphic reactions, and is scattered far and wide throughout the limestone.

Tourmaline is generally found in the intrusive rock as an endomorphic mineral, also in small scattered crystals in the limestone, or as a massive constituent of nodules far from a contact. It is black or brown, irrespective of its occurrence in the limestone or in the intrusive.

Chondrodite and spinel are usually found together, though chondrodite may occur without the other. They are at some distance from the intrusive, and generally occur alone or with serpentine, which is secondary after chondrodite. Serpentine and chondrodite may occur in nodules along with scapolite and other silicates.

Graphite occurs scattered as flakes throughout the limestone, but more particularly as concentrations in the limestone near to a contact, frequently in nodules along with other silicates, and not rarely as a constituent of the pegmatite or quartz veins.

Localities in the Granite Area Outside of the Oxbow District.

69–A. Northeast of Macomb, near the northeast corner of the Hammond Quadrangle, there is a limestone valley lying to the west of Beaver Creek. This belt of limestone is considerably interrupted by sills and dikes of pegmatite, and contains many impurities in the form of scattered diopside, phlogopite, quartz, and graphite. Large

quartz veins are also prominent. They cut across both the pegmatite and the limestone. Some of them contain considerable tourmaline in large, well-developed, elongated crystals, with the characteristic curved triangular outline. At one locality two crystals were found which had a core of quartz. In one of these the quartz ran through the center of the crystal, which was about an inch long. In the other the quartz was at one end and the crystal was splayed out to hold it, as though the quartz had crystallized later and forced it out. Brown tourmaline is found in quartz, and very dark brown to nearly black tourmaline crystals, with zonal growth, occur in the limestone. The zonal growth is irregular, and shows a black surface with an unevenly developed brown core. Occasional quartz veins in this region contain small concentrations of pyrrhotite.

The minerals:

Tourmaline ...	light brown.	$\omega = 1.637 \pm .003$ $\epsilon = 1.618 \pm .003$	$\omega - \epsilon = .019.$
	dark brown.	$\omega = 1.643 \pm .003$ $\epsilon = 1.622 \pm .003$	$\omega - \epsilon = .021.$
Felspar (dike).	Microcline.	$\gamma = 1.530 \pm .003$ $\alpha = 1.522 \pm .003$	$\gamma - \alpha = .008.$
	Orthoclase.	$\gamma = 1.525 \pm .003$ $\alpha = 1.520 \pm .003$	$\gamma - \alpha = .005.$
	Albite.	$\gamma = 1.534 \pm .003$ $\alpha = 1.530 \pm .003$	$\gamma - \alpha = .004.$

69–F–2. Near the southeast corner of the Hammond Quadrangle, on the northwest side of the state road between Antwerp and Gouverneur, just north of Somerville, there is an old quarry which cuts through the contact between porphyritic granite and marble.

Near the contact the intrusive has developed a greenish-gray syenitic facies, composed of oligoclase, microperthite, a little quartz, biotite, and phenocrysts of deep green hornblende.

Small lenses of a fine-grained variety of this rock pass out into the limestone, and sometimes develop a scapolite-hornblende facies. A fibrous wernerite is the chief result of the alteration of the marble, and occurs both at the contact of the lenses and as nodular zones within a few feet of the contact. This is accompanied by varying amounts of diopside, phlogopite, hornblende, and graphite.

A. Quartz network in limestone. 69-K-11. See p. 30.

B. Limestone projecting down into pegmatite dike. See Fig. 1, *B*, for details.

The minerals:

Wernerite ....fresh. This is a wernerite near the Meionite end of its range.

$$\left.\begin{array}{l}\omega = 1.572 \pm .003\\ \epsilon = 1.548 \pm .003\end{array}\right\} \omega - \epsilon = .024.$$

also greenish, fibrous, altered. This is intergrown with quartz and partially altered to minute, high birefracting scales which are probably muscovite.

$$\left.\begin{array}{l}\omega = 1.573 \pm .005\\ \epsilon = 1.547 \pm .005\end{array}\right\} \omega - \epsilon = .026.$$

Hornblende ..$\left.\begin{array}{l}\gamma = 1.656 \pm .003\\ \alpha = 1.638 \pm .003\end{array}\right\} \gamma - \alpha = .018,\ Z \wedge c = 17°.$

Felspar ......very rare brownish oligoclase.

$$\left.\begin{array}{l}\alpha = 1.541 \pm .003\\ \gamma = 1.547 \pm .003\end{array}\right\} \gamma - \alpha = .006.$$

Some microcline.

69–F–3 and 4. To the southwest of the right angle turn in the road running northwest from the state road, along the township boundary line, there is a 300-foot by 25-foot pegmatite sill in the edge of the woods; and 300 feet south of that a small granite stock, roughly 180 feet in diameter, cutting the limestone. In the limestone between these two there are a large number of nodules composed of contact silicates.

There is no contact metamorphism exactly along the borders of the pegmatite sill, though bands of coarsely crystalline silicates parallel the southern contact at a distance of a few yards. The east end of the sill divides and includes a bed of limestone. This has suffered no alteration excepting a very slight crystallization.

The numbers in the appended mineral description refer to Fig. 3 *A*.

The minerals:

F–3–c. A band of phlogopite, some crystals several inches in cross-section.

F–3–d. A shorter and more irregular zone composed of:

Phlogopite.

Wernerite—gray, fibrous.

$$\left.\begin{array}{l}\omega = 1.577 \pm .003\\ \epsilon = 1.544 \pm .003\end{array}\right\} \omega - \epsilon = .033.$$

Tourmaline—brown.

$$\left.\begin{aligned}\omega &= 1.640 \pm .003\\ \epsilon &= 1.617 \pm .003\end{aligned}\right\}\ \omega - \epsilon = .023.$$

There are also a few small, prismatic, grayish crystals in calcite, which are uniaxial, have low B., and $\omega = 1.640 \pm .003$. Probably a nearly colorless tourmaline.

Spinel.

Serpentine.

Tremolite—dark, fibrous, admixed with calcite.

F–3–e. Zone holding large phlogopites and green serpentine with some unaltered chondrodite. The serpentine is an alteration product of chondrodite.

F–3–f. Wernerite—grayish, fibrous.

$$\left.\begin{aligned}\omega &= 1.577 \pm .003\\ \epsilon &= 1.549 \pm .003\end{aligned}\right\}\ \omega - \epsilon = .028.$$

Phlogopite.

Tourmaline—reddish brown.

F–4–b. White marble holding small reddish-brown crystals of diopside, which are arranged more or less linearly with graphite.

Diopside— $$\left.\begin{aligned}\alpha &= 1.669 \pm .003\\ \gamma &= 1.698 \pm .003\end{aligned}\right\}\ Z \wedge c = 37^\circ.$$

F–4–d. Wernerite—gray, white, fibrous.

$$\left.\begin{aligned}\omega &= 1.577 \pm .003\\ \epsilon &= 1.549 \pm .003\end{aligned}\right\}\ \omega - \epsilon = .028.$$

Meionite— $$\left.\begin{aligned}\omega &= 1.588 \pm .003\\ \epsilon &= 1.553 \pm .003\end{aligned}\right\}\ \omega - \epsilon = .035.$$

Missonite, whitish—

$$\left.\begin{aligned}\omega &= 1.565 \pm .003\\ \epsilon &= 1.547 \pm .003\end{aligned}\right\}\ \omega - \epsilon = .018.$$

Hornblende—deep shiny brown with a red tinge. Silky pargasite.

$$\left.\begin{aligned}\alpha &= 1.627 \pm .003\\ \gamma &= 1.650 \pm .003\end{aligned}\right\}\ \gamma - \alpha = .023,\ Z \wedge c = 25^\circ.$$

Tourmaline—black (rare).

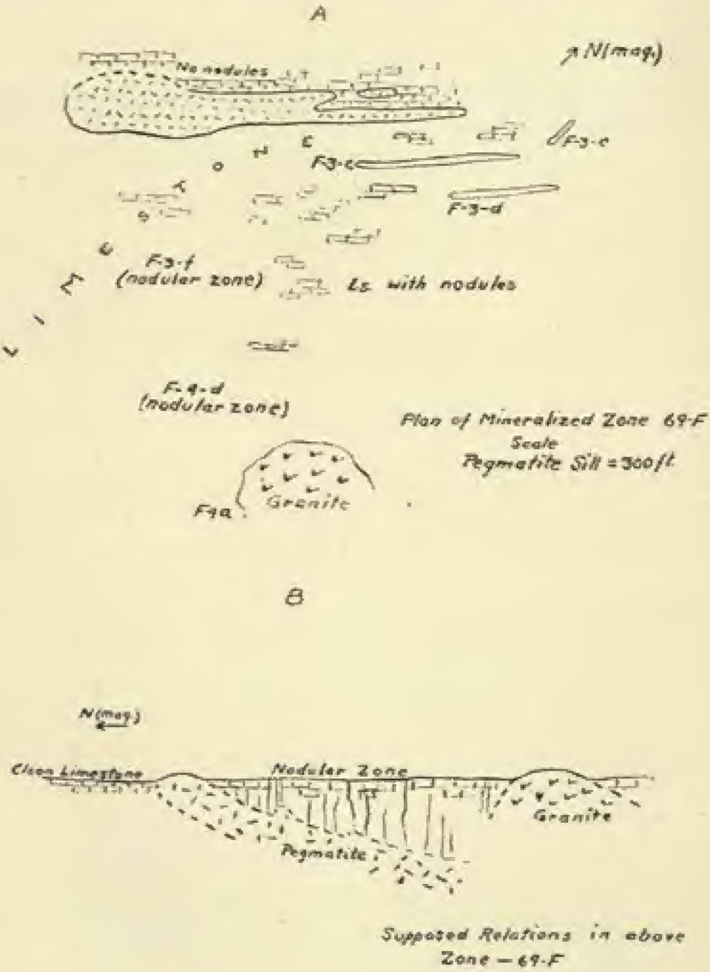
Tourmaline—brown (common).

Fig. 3 *B* shows the supposed relations of the intrusives to the nodular zones and to the limestone free from nodules.

Southwest of here, in the triangle of roads south of Wegatchie, Professor Buddington found small, nearly colorless crystals of

tourmaline disseminated over a large surface area of limestone. These are associated with the usual phlogopite and tremolite. The indices of this tourmaline are:

$$\omega = 1.634 \pm .003, \quad \epsilon = 1.615 \pm .003, \quad \omega - \epsilon = .019.$$



The same scattered minerals are found to the east and northeast of the "F" area. It is a region of comparatively few pegmatite dikes, which have had little or no metamorphosing power at their

immediate boundary. Chondrodite, phlogopite, and an occasional brown tourmaline are found here and there in the limestone.

69–M. On a bare hillock in the center of a field, three quarters of a mile northeast of Grass Lake, on the western edge of the Hammond Quadrangle, south of the center, there is a coarsely crystalline aggregate of pyroxene, felspar, titanite, and calcite, with considerable quartz and a one-half-inch vein of fluorite in quartz. These minerals occur in an amphibolite which has been penetrated by acid pegmatite juices. The calcium carbonate must have been brought up with the pegmatite from marble beds traversed below. The amphibolite appears to have played no part, except perhaps that of furnishing a zone of weakness and thus localizing the solutions.

The minerals:

Diopside .....crystals as large as six inches in cross-section.

$$\left.\begin{array}{l}\alpha = 1.684 \pm .003\\ \gamma = 1.710 \pm .003\end{array}\right\}\gamma - \alpha = .026.$$

Calcite ....large cleavage pieces.

Phlogopite.

Quartz.

Felspar ......andesine.

$$\left.\begin{array}{l}\alpha = 1.546 \pm .003\\ \gamma = 1.553 \pm .003\end{array}\right\} \begin{array}{l}\gamma - \alpha = .007.\\ \text{Rare Microperthite.}\end{array}$$

Titanite.

Fluorite ......purple, isotropic. η far below 1.475.

Fluorite has been reported by C. D. Nims from the following areas of indefinite extent: Macomb, Rossie, Fine, Muskalonge Lake, and, in addition, by Dana at De Kalb. Except for weathered blue-green fragments of fluorite picked up along the shores of Muskalonge Lake, the above is the only occurrence noted by the writer.

69–H–1. On the old Reese Farm, two miles southwest of Richville, there is an irregular development of minerals, predominantly brown tourmaline and tremolite, in a lenticular pinching and swelling zone in marble. This is the famous Gouverneur brown tourmaline locality. Several distinct pits have been dug in it. The brown tourmaline occurs chiefly as one component of a massive mixture of earthy, white diopside, calcite, silky white tremolite, and tourmaline; but it can also be found in clear, amber-colored crystals several inches

long. The diopside forms opaque, white, octagonal crystals, and the tremolite occurs as beautifully bladed, shiny white prisms several inches long, and grouped into individuals an inch or more broad. A little apatite, phlogopite, and grains of pyrrhotite are also found in this mass. The surrounding limestone, within a radius of at least 200 yards of these pits, is full of irregularly oriented, needle-like tremolite crystals.

Two knobs of pegmatite, composed of quartz, felspar, and a little black tourmaline, barely project above the ground twenty-five yards northeast of the mineral pits and well within the radius of tremolitization of the limestone. The longest diameters of these knobs point toward each other, and suggest that they are the upward extensions of a dike or sill which is roughly parallel to the mineral zone.

The minerals:

Brown tourmaline.......... $\left.\begin{array}{l}\omega = 1.637 \pm .003 \\ \epsilon = 1.618 \pm .003\end{array}\right\} \omega - \epsilon = .019.$

Tremolite .... $\left.\begin{array}{l}\gamma = 1.625 \pm .003 \\ \alpha = 1.606 \pm .003\end{array}\right\} \gamma - \alpha = .019.$

Diopside ....badly altered.

Apatite .... $\left.\begin{array}{l}\omega = 1.630 \pm .003 \\ \epsilon = 1.628 \pm .003\end{array}\right\} \omega - \epsilon = .002.$

Phlogopite.

The marble away from the tremolitized area is remarkably pure, and shows only rare specks of quartz and phlogopite in thin section.

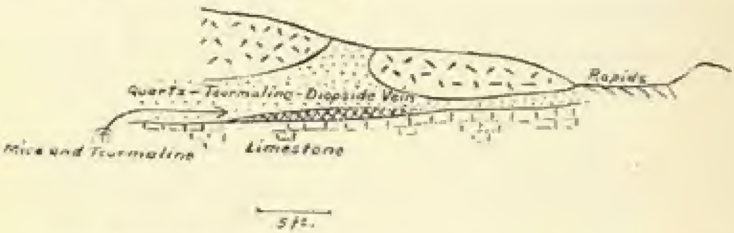
69–Q–2–a. One and one tenth miles north-northwest of Pierrepont crossroads, near the central western edge of the Canton Quadrangle, there is a concentration of black tourmaline, diopside, hornblende, and phlogopite in a gangue of quartz, calcite, and dolomite. This is the well-known Pierrepont black tourmaline locality.

The minerals form an irregular band, winding up the hillside for one hundred yards, and are exposed over most of the distance. Tourmaline is the predominating mineral at the lower end, but phlogopite replaces it toward the upper end. The tourmaline is found in short, jet black, often doubly terminated, shiny crystals, with markedly polar characters.

Most of the hillside is covered by sod, and there is nothing in the immediate vicinity to show the origin of the vein except that sug-

gested by the minerals themselves. Quartz and tourmaline, with diopside and phlogopite, are constant associates of the granite pegmatites. Hornblende is occasionally found with them.

Fifty yards down the slope, in the bed of Leonard Brook, and striking toward the mineral zone, a pegmatite dike intersects the limestone and a garnet gneiss. This dike is in turn cut by a quartz, tourmaline, phlogopite, diopside vein, and shows a marked concentration of stubby, polar tourmaline crystals and phlogopite along its contact with the limestone. See Fig. 4.



Pegmatite Dike in the bed of Leonard Brook at G-2-a

The hill west of the brook is a garnet gneiss and an amphibolite of unknown origin. These are locally full of granite injections, and contain a few tourmaline-bearing pegmatite dikes. The limestone adjoining this mass on the west contains some serpentine and spinel.

The widespread occurrence of phenomena connected with the granite intrusions, the presence of a dike of granite pegmatite containing the typical tourmalines along with phlogopite and diopside (a dike which, if prolonged, would come very near to the greatest development of tourmalines), is regarded as proof that the minerals owe their origin to the magmatic solutions accompanying the granite.

The minerals:

Tourmaline . . . black. $\omega = 1.650 \pm .003$ — complete absorption of light along ϵ ray.

Diopside . . . . . square crystals.

$$\left.\begin{array}{l}\alpha = 1.670 \pm .003\\ \gamma = 1.700 \pm .003\end{array}\right\} \gamma - \alpha = .030,\ Z \wedge c = 39^\circ.$$

hydrated. $$\left.\begin{array}{l}\alpha = 1.613 \pm .003\\ \gamma = 1.632 \pm .003\end{array}\right\} \gamma - \alpha = .019.$$

Hornblende . . . $$\left.\begin{array}{l}\alpha = 1.620 \pm .003\\ \gamma = 1.642 \pm .003\end{array}\right\} \gamma - \alpha = .022,\ Z \wedge c = 18^\circ.$$ Slight pleochrism.

Dolomite .....rhombohedral cleavage, effervesces strongly with concentrated hydrochloric acid, but only very slightly with dilute hydrochloric acid.
$\omega = 1.680 \pm .005$.
$\epsilon = 1.540$.

69–Q–1. One mile southeast of the village of Pyrites there are a number of old dumps of phlogopite with crystals four inches in diameter and irregular plates of larger size. These occur in the zone of amphibolite and garnet gneiss surrounding the Laurentian granite of that area described by J. C. Martin.[6]

This is intersected by a few large pegmatite dikes, and a number of smaller ones bearing black tourmaline. The small dikes are not seen cutting the large ones, and may be of the same or different age.

The large pegmatite dikes, the contact garnet gneiss, and the amphibolite are all crossed by a banded vein consisting of pyroxene, biotite, calcite, and apatite. This vein varies from nearly four feet in thickness to complete disappearance, and is uniformly banded as follows.

The measurements were taken from wall to wall by Professor Buddington.

4 three fifths of an inch of pyroxene.
3 three inches of elongated fiber-like mica and pyroxene.
2 three inches of pyroxene and apatite.
1 from nothing up to one foot of coarse mica.
0 one foot coarse calcite holding apatite.
1 from nothing up to one foot of coarse mica.
2 three inches of pyroxene and apatite.
3 three inches of elongated fiber-like mica and pyroxene.
4 three fifths of an inch of pyroxene.

Titanite and well-developed crystals of wernerite two inches long and one inch thick were found in loose pieces of pyroxene and calcite, and evidently came from near the middle of the vein.

The development of good crystals of pyroxene, apatite, and titan-

[6] Martin, J. C., "Pre-Cambrian Rocks of the Canton Quadrangle," N. Y. State Mus. Bull. 185, Albany, 1916.

ite, together with the perfection of the banding, make it difficult to see how this vein could have been formed under conditions of high pressure. The banding is that of a true fissure-filled vein.

It has been claimed that the force of crystallization of minerals will wedge and hold the walls of a fissure apart, and thus allow minerals to form. But, as brought out by Lindgren ("Mineral Deposits," p. 656), "aside from the problematic intensity of this force, such crystallization could hardly have produced perfect crystals or drusy structure." Lindgren favors the hypothesis that the vein-forming solutions were injected under pressure and so made a space for themselves, like pegmatite dikes; but even under those conditions he says (Lindgren, *op. cit.*, p. 657): "The texture of the veins is generally coarse grained and irregular. There may be a rude banding by deposition, but nothing to equal the delicate concentric banding of the veins formed near the surface."

Typical high temperature minerals occurring in a banded vein deposit are rare, and clearly indicate the wide range of conditions under which these minerals may be formed. This vein must represent a later phase than the typical contact zones of the region. Its peculiarities are believed to result from decrease of pressure rather than of temperature.

69–P–2. Four and a quarter miles southwest from Russel, and one fifth of a mile southeast from the road between Russel and Edwards, there occurs a concentration of the rare mineral danburite, as beautiful crystals and as a massive vein mineral in a pyroxene schist. Mention is made of this in C. D. Nim's manuscript as follows: "Danburite in magnificent crystals, some of the smaller size perfect gems, brilliant, transparent, beautifully modified, some of the larger are five inches in diameter and a foot long." There is nothing comparable to this to be found here now, unless blasting should reveal new masses of it.

The geology of this region was not studied in enough detail to be able to refer this occurrence to any particular intrusive, but it is mentioned here as giving added proof of the concentration of large quantities of boron in the magmatic vapors and solutions of the region.

General Summary of the Area of Granitic Intrusives.

The areas described above show a multiplicity of detail, but, underlying this, there is a general marked similarity of occurrence in widely separated localities. Everywhere a rock of granitic character has intruded a limestone and, in comparatively few places, contact metamorphic minerals have been formed both near to and far from the contacts. The rare elements which so often characterize granite pegmatites are lacking. The minerals are very limited in number and most of the species are constant over the whole area. Particular associations between minerals are very few, and age relations such as to show successive periods, or waves, of metamorphism are lacking.

The fundamental problem is to determine what cause or causes acted to bring about the formation of these minerals, their peculiar distribution, and their absence over long miles of contact.

At first glance it would appear probable that a difference in composition of separate parts of the limestone or of the intrusive would easily explain such a variation. But an examination of very little of the many miles of contacts shows how a local mineral area can be followed on either side by a totally barren contact. No variation in the country rock can account for such sudden and marked changes as that.

There is no denying, however, that the composition of the limestone does vary from place to place. This variation is twofold. In the first place, the content of magnesia changes; and, secondly, there is probably an increase and decrease of the siliceous impurities contained.

D. H. Newland[1] has the following to say concerning the limestones of the Adirondacks: " It is a calcite limestone with a variable but generally small amount of magnesia. The carbonates amount to about 95 per cent. of the whole mass, of which nearly 90 per cent. is calcium carbonate. Rarely the magnesia assumes sufficient importance to characterize the rock as a dolomite." Analyses published in his report give the percentages of magnesian carbonate as 6.40 per cent., 7.50 per cent., 6.85 per cent., and calcium carbonate as 87.09

[1] "Quarry Materials of New York," by D. H. Newland, New York State Museum Bull. No. 181, Albany, 1916.

per cent., 87.47 per cent., 89.94 per cent., respectively, in three of the Gouverneur marbles. In Harrisville, Lewis County, magnesium carbonate is given as 21.79 per cent., and calcium carbonate as 79.17 per cent. This latter is a true dolomite of very local character.

The following partial analyses were made by the writer:

Marbles. (1) 69–H–1–a, white, recrystallized calcite from among the silicates.

$$CaO = 56.45.$$
$$MgO = 2.49.$$

(2) 69–H–1–c, limestone near H–1–a, but not quite on the same strike.

$$CaO = 52.24.$$
$$MgO = 3.80.$$

(3) 69–V–4–b–4, white marble containing disseminated silicates from Natural Bridge.

$$CaO = 54.97.$$
$$MgO = 1.13.$$

(4) 69–K–7–a–2, white marble from a limestone-chondrodite zone.

$$CaO = 52.36.$$
$$MgO = 2.38.$$

(5) 69–K–13–c, limestone far from any mineral development.

$$CaO = 51.02.$$
$$MgO = 4.12.$$

These show the variable though generally very low percentage of magnesia. There appears to be a tendency toward lower magnesia when the sample was taken from a mass containing silicate minerals than when it was taken from pure limestone. Samples 1, 3, 4 are lower in magnesia than Nos. 2 and 5.

In discussing the percentage of siliceous impurities in the limestone preceding the intrusion of the granites we are treading on thin ice. There have been two periods of metamorphism superimposed one upon the other, and the effects of the second, the regional contact

metamorphism, have so masked those of the first, the dynamo-metamorphism, that it is impossible to determine the chemical composition or physical condition of the sedimentary series at the beginning of contact metamorphism.

Certainly the original metamorphism transformed a fine-grained, detrital, or chemically precipitated limestone into a crystalline marble. The thoroughly crystalline condition of the sediments accompanying the limestone suggests that this early metamorphism proceeded to the stage where the development of silicates by recrystallization took place in them, but it can not be definitely stated to be so. All the minerals existing at present in the limestone can have been formed by contact metamorphism, and certainly most of them were so formed; but the possibility of the earlier existence of such silicates as phlogopite, diopside, and tremolite in scattered crystals must be recognized, and, if they existed, their quantity would doubtless vary from place to place.

Carbonaceous matter is also believed to have existed originally in the rock. During the contact metamorphic stage it underwent a concentration as graphite at the contacts, in bands parallel to them, sometimes in the dikes, and frequently in nodules along with contact silicates.

The presence of tourmaline and chondrodite in the regions of scattered minerals and the widespread occurrence of fluorine in the micas prove beyond question the influence of mineralizers on the formation of such scattered silicates. The general purity of the limestone removed from such signs of direct magmatic additions suggests that the crystalline impurities can not have been very plentiful anywhere, or else that the magmatic additions always took place where the limestone was already impure. It is hard to credit the latter.

Some quartz is believed to be due to the recrystallization of originally siliceous layers, but in that case it occurs as bands or as a network in the limestone. On the other hand, there is a great deal of quartz, accompanied by a little felspar, which clearly replaces the limestone and which was added at a late date in the period of igneous activity and which grades into the pegmatites.

It is believed, then, that the limestone, at the start of contact metamorphism, was coarsely crystalline, contained local areas of banded quartz, an unknown though small quantity of phlogopite, diopside, and tremolite, and a considerable quantity of carbonaceous material.

Accompanying, or subsequent to, the large intrusions of granite, the pegmatites came in. These, in the nature of residual magmas, contained the principle elements of the igneous rock and a concentration of volatile substances, chief among which were water and compounds of boron, fluorine, chlorine, phosphorous, and some sulphur. The rarer elements such as tin, tungsten, tantalum, etc., so often characteristic of pegmatites were lacking.

These residual magmas were cooler than the original magma at the start, but, because of their high fluidity, they existed long after the border of the parent rock had crystallized and were injected into it and into the sediments as dikes and sills, the gases or vapors passing even further out into the limestone. As more and more material was crystallized the residual matter, even cooler and more dilute, took on the nature of vein solutions, and finally, having passed from the pegmatite stage, formed high temperature quartz veins holding occasional tourmalines, felspars, and pyrrhotite. Still later than this, solutions containing only silica and a very little of the constituents of felspar passed out into the limestone and replaced it.

The vast amount of magmatic vapors which worked out into the limestone has resulted in the development of contact metamorphism on a regional scale. There is nothing in the field to distinguish the minerals formed at different periods during the progressive cooling of the vapors, but they can not have been all formed at one time, and the existence of the extraordinary banded vein deposit at Pyrites (69–Q–1–a), containing the minerals formed elsewhere under conditions of high temperature and pressure, suggests a considerable range of conditions under which these contact silicates may be formed.

The presence of the mineralizers does not explain the localization of the minerals and the many miles of barren contact. According to Barrell,[8] " Carbonic acid is only expelled where the siliceous impuri-

[8] " Physical Effects of Contact Metamorphism," J. Barrell, *American Journal of Science*, Vol. 13, 4th Series, 1902, pp. 279–296.

ties of the limestone are sufficient to combine with the lime set free forming lime silicates. This ability of deeply buried limestones to retain their carbonic acid when intensely heated, if free from other impurities, has been noted by a number of observers. . . ." In the present case the marble was already dense, crystalline, stable under metamorphic conditions, and the impurities were probably already segregated as minute crystals. Heat alone would have no effect upon it. Water vapor bearing silica and other constituents of the magma plus the mineralizers boron, fluorine, chlorine, and phosphorous should react with the calcium and magnesium carbonates, thus setting free the carbon dioxide.

Eskola[9] says: "The resistance offered by limestone against the granitization is very remarkable. Even in the midst of a migmatite area, where all the siliceous rocks have been thoroughly mixed or assimilated with the granite magma, the limestones are generally quite free from granitic injections, and are intersected only by rectilinear pegmatite dikes."

Lindgren[10] claims that, "Even where the carbon dioxide can not escape there may be intense action between the igneous rock and the limestone. The two rocks will form a chemical system with great difference of temperature and it may be assumed that there will be intense transfer of material between the two." He also states that if the solutions are dilute enough nothing but a recrystallization of impurities will take place.

In the western Adirondacks it is probable that the limestone was deeply buried and therefore molded and recrystallized at the existing temperature and pressure to form a relatively impervious barrier, except locally, to the formation or penetration of the magmatic vapors, particularly so along the contact with the intrusive. Locally a reaction was set up which resulted in the formation of a narrow zone of coccolite and occasionally a mineral concentration; but, over most of the contact, limestone exists against granite or pegmatite without even a coarsening of the crystallization to mark the position of the intrusive. The replacing quartz veinlets may have been

[9] "On the Petrology of the Orijarvi Region in Southwestern Finland," Pentti Eskola, *Bull. de la Comm. Geol. de Finlande*, Avril, 1914, p. 36.

[10] Lindgren, W., "Mineral Deposits," p. 722.

formed by a more thinly fluid magmatic portion richer in water working its way into position, in part at least, by metasomatic replacement.

The intrusion of the pegmatites was accompanied by folding of the limestone in many places, and it is reasonable to suppose that it caused the development of crushed zones and of lines of weakness. We must turn to this for an explanation of the peculiar localization of the contact phenomena. In such a zone the pressure would be reduced, magmatic vapors released, and a channel for the escape of carbon dioxide offered, thus allowing an interaction between the materials of the rock and the magmatic solutions.

But there are still two distinct types of contacts formed by these means to be explained. First, the complete alteration of a narrow band of limestone, with a maximum width of six inches, at the immediate contact; and, secondly, the pocket and nodule type either on the contact or surrounded by limestone and far from any visible intrusive. Massive wernerite or diopside predominates in the first of these, sometimes forming the whole mass of the rock as at K–7–b–1, or along with phlogopite as at K–6–a–4, or phlogopite and apatite as at K–2–a–6. In these cases there is little or no calcite left. The division between the contact rock and the unaltered limestone is very sharp and endomorphic effects are liable to be marked. These contacts grade into the next type through a few, such as K–5–b and K–8, where there is considerable calcite left in a predominantly silicate mass a foot or two thick with an irregular development.

The second type is the common one. Nodules, bands, and pockets of most of the contact minerals are found indiscriminately intergrown along the edge of a dike, in the limestone along a contact, or far out as an islet in the limestone.

In the first case there has been an addition of silica, chlorine, fluorine, alumina, soda, and probably some phosphorous, with the complete expulsion of carbon dioxide and some lime and magnesia at the immediate contact.

Leith and Mead [11] quote from Ingersoll and Zobel to the effect that heat advances very slowly. "The maximum temperature in limestone, or the crest (so to speak) of the heat wave, travels out-

[11] "Metamorphic Geology," by Leith and Mead, p. 144.

ward only a few centimeters a year. The mass behind it will then suffer a contraction as soon as it begins to cool, and the cracking and introduction of mineral-bearing material is doubtless a consequence of this." It may be in such an action that we find the cause of these complete replacements, though even at the start, as shown by the lack of chill zones, the temperature difference can not have been very great, or it may be in a more sudden shattering on intrusion.

In the second case the mineralizing solutions have followed fractures or zones of weakness which have allowed the interaction between the carbonates and the introduced silicates with their accompanying mineralizers. These pocket and nodule areas are probably all connected with igneous derivatives in depth.

The abundance of tourmaline and chlorine and fluorine bearing minerals shows the presence of large quantities of volatile substances. Probably they were associated with large quantities of silica and some soda, potash, and alumina. There is evidence that part at least of the magnesia in the minerals of the region was derived from magmatic additions. This is true in the case of dolomite matrix at Pierrepont, and, as shown later, in the case of the dolomite band in the quarry 69–V–4–b–4 at Natural Bridge.

All that was needed in any instance to start the reaction between silica and the calcium and magnesium carbonates, and the formation of pneumatolitic minerals, was a channel of escape for these vapors out into the limestone and for the carbon dioxide from the limestone, or, at least, from that immediate vicinity.

The vapors were of varying composition or of variable concentration, for they reacted differently in immediately adjacent localities. Scapolite very high in the meionite component occurs alongside of scapolite high in marialite. Brown and black tourmalines occur in one nodule six inches across, and tremolite and diopside are everywhere intergrown. These differences can not be attributable to original differences in composition of the limestone.

There are no evident age relations between the various minerals. They are intergrown and practically contemporaneous. Occasionally phlogopite is found as small crystals in later silicates. In the same

contact it will be found in large crystals intergrown with the later minerals. It is either of two generations, or, possibly, the inclusions represent impurities crystallized during the regional metamorphism and stable under the new conditions.

The only age difference is that due to the time taken by the vapors to work their way out into the limestone—probably negligible, though the factor of internal pressure may have retarded them.

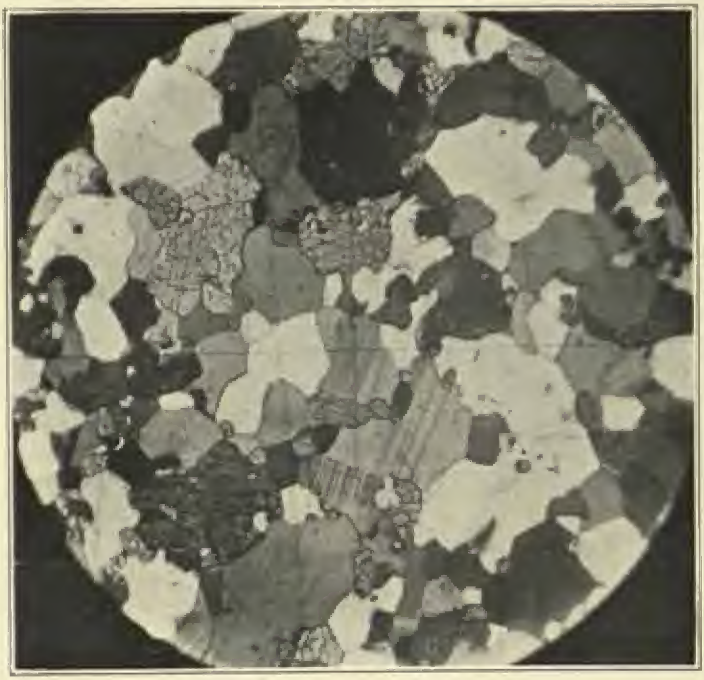
Along with the formation of these minerals there went a recrystallization of the calcite. This now occurs as the country rock, replaced by the silicates, as crystals of the same generation as the silicates, and, very rarely, replacing the silicates.

Subsequent to the formation of the contact silicates, and probably after the internal pressure had returned to normal and most of the channels of escape of carbon dioxide had been sealed up by silicates, there occurred an exudation of heated solutions containing little else than silica; and quartz was deposited by metasomatic replacement, sometimes among the earlier silicates, but chiefly in the limestone. This was accompanied by a very minor amount of soda, potash, and alumina which combined with silica to form microcline and microperthite.

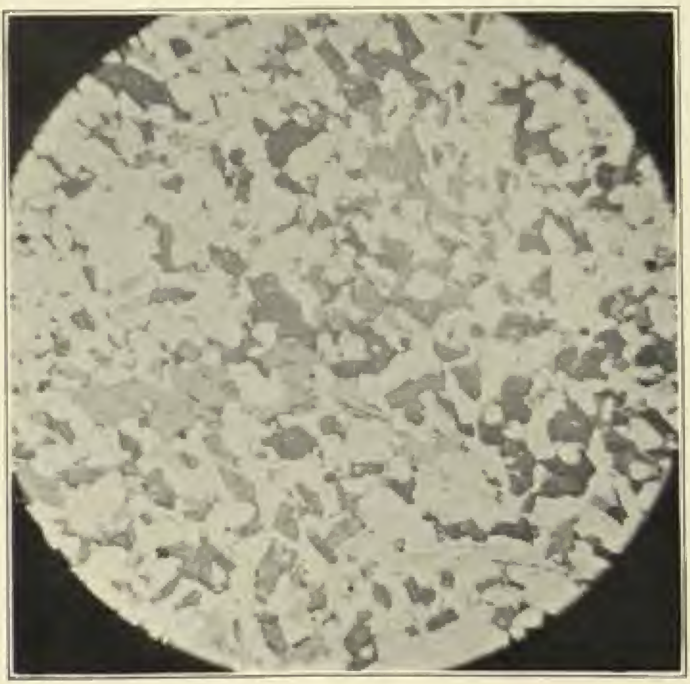
Possibly the temperature of this solution of silica was too low to react with the limestone, but more likely the absence of channels for the escape of carbon dioxide prevented the reaction and caused the quartz and a little felspar to replace the limestone volume for volume. The same solution which brought in the replacing constituents removed the calcium carbonate and so the replacement crept slowly out into the rock.

The quartz dikes, on the other hand, generally cut the limestone sharply and belong to the period of intrusion of the pegmatites, though they appeared at a late date in that period.

At a time still later than that of the replacement by quartz and felspar the quartz was granulated and strained and the felspar distorted. A recrystallization of calcite accompanied this distortion and a replacement of quartz, felspar, and sometimes phlogopite, by calcite took place on a very small scale. Some quartz in the limestone was



A. Endomorphic edge of the diorite C-6-a, Rossie. Felspar, Pyroxene, Titanite. (Crossed Nicols (see p. 63), $\times$ 20.)



B. Hornblende-mica-diorite C-6-c, Rossie. Dark gray = hornblende and some mica. Light gray = mica. White = felspar. Ord. light, $\times$ 20.

replaced along its edges by minute specks of calcite and a low birefracting mineral which is probably quartz differentially oriented from the large fragment.

These replacements and crystallizations were very likely connected with later deformations in the Adirondacks. The granulation of the quartz and the felspar certainly occurred when the limestone was comparatively cool and under no great pressure. Considerable shearing must have taken place, though the recrystallization of the limestone has hidden it.

The Rossie District.

North of the village of Rossie we find a different set of conditions represented. This locality lies in the north center of the Hammond Quadrangle immediately southeast of Grass Creek and west of the Rossie-Hammond road where it crosses that creek.

Dikes and veins associated with the granite intrusives are still plentiful. Their influence is seen in the development of large plates of mica and the minerals tremolite and zircon listed by Nims, but the minerals to be discussed occur with a rock of intermediate composition.

The mass of this rock consists of biotite, amphibole, with some residual pyroxene, alkalic plagioclase, apatite, titanite, and an occasional garnet. Owing to the fact that the geology of this particular region has not been studied in detail, no evidence as to the original composition of this rock has been found beyond that given by the microscopic examination of specimens of the two outcrops here described. Its intrusive character is established beyond question by the fact that it cuts across and breaks through the limestone without regard to preëxisting structure.

The present composition of the rock is that of a hornblende-mica-diorite (Plate XI (*B*)), but the secondary nature of some of the minerals is evident under the microscope. Professor Smyth,[12] who has discussed the origin of this rock, says:

[12] "The Genetic Relation of Certain Minerals of Northern New York," C. H. Smyth, Jr., *Transactions N. Y. Acad. Sci.*, Vol. XV., Sig. 17, Sept. 25, 1896, pp. 260-270.

Thin sections of the gneissoid rock entirely substantiate the conclusion that it is of igneous origin. It consists of hornblende, biotite, and plagioclase, with considerable titanite, some apatite, and occasional grains of garnet. The hornblende sometimes contains a little colorless pyroxene, evidently all that is left of larger amounts of the mineral that have changed to hornblende. This fact, coupled with other cases in the region, suggests that the rock may have been originally a gabbro; but there is no proof that such was the case, and it must be classed as a hornblende mica diorite.

Biotite is plentiful and occurs as elongated pleochroic individuals.

The amphibole is a deep blue green and is strongly pleochroic. Its birefringence is low and its extinction high. Its indices of refraction are difficult to determine accurately owing to the color and to the strong absorption of the γ ray. The optical properties determined are as follows:

$\alpha = 1.666 \pm .003.$
$\beta = 1.674 \pm .005.$
$\gamma = 1.680 \pm .005$, $\gamma - \alpha = .014$. Opt. (—), $Z \wedge c = 34°$.
Pleochroism—α = light yellow green.
β = dark yellow green.
γ = dark blue green.

β approaches γ more closely than it approaches α, but could not be determined with sufficient accuracy to permit the computing of the angle 2V.

This combination of pleochroism, extinction, and indices shows the mineral to be different from any other amphibole whose published properties could be found, yet the perfect 124° cleavage exhibited by some fragments in thin sections cut from the body of the rock, as well as in a hand specimen of this amphibole from the contact zone, shows that it belongs to this group. In view of these facts, Professor Phillips kindly undertook to make a complete analysis of the mineral. The material submitted to him for analysis was ground and carefully examined under the microscope. It was found to contain very rare flakes of phlogopite and a totally negligible percentage of titanite. The combined effect of the impurities can not impair the results of the analysis.

Professor Phillips's analysis is given under Table I.:

I.		II.	III.
SiO_2	=41.68	42.40	−0.72
TiO_2	=00.72		
Al_2O_3	=11.02	10.40	+1.48
Fe_2O_3	=10.77	6.00	+4.77
FeO	= 6.40	14.75	−8.35
MnO	= 0.36		
CaO	=12.01	11.75	+0.62
MgO	=10.09	10.90	−0.81
Na_2O	= 4.30	3.75	+3.20
K_2O	= 2.65		
H_2O	= 0.09		
	100.09		

In 1914, W. E. Ford [12] published the results of an optical study and chemical analyses of a series of amphiboles. On page 181 of that paper he gives a series of ten analyses of "normal" and typical amphiboles. Upon studying his optical determinations he concludes that "the variation in the mean index of refraction came nearer to showing a correlation with the variation in composition than any of the other optical characters." He also gives nine figures showing the results of the analyses in graphical form with the percentages of the different radicals present in the minerals forming the ordinates, and the mean indices of refraction the abcissas.

These figures were used by the writer to compute roughly the chemical composition of an amphibole with a mean index equal to 1.673, that of the amphibole under discussion. This is given in Table II. Table III. shows the amounts by which Professor Phillips's analysis differs from the computed average for the "normal" amphibole.

An inspection of this table will show that the silica, alumina, lime, and magnesia are well within the limits of error of the computed percentages, but ferric iron and the combined alkalies are much higher, while ferrous iron is low. The latter represents the greatest difference and results in the combined oxides of iron being three and one half per cent. too low.

A glance at the analyses of amphiboles given in Iddings's "Rock Minerals" and Dana's "A System of Mineralogy" soon shows that

[12] "A Contribution to the Optical Study of the Amphiboles," *Am. Jour. of Sci.*, Vol. XXXVII., Feb., 1914.

this amphibole is too high in soda, potash, and alumina for a normal hornblende, and that it differs from the alkaline amphiboles by containing much too high a percentage of magnesia and alumina—this latter with a few exceptions—and much too low a percentage of ferrous iron. It is also entirely out of the tremolite and actinilite groups because of too much total iron and alumina and too little magnesia.

W. E. Ford [14] gives the analysis and the optical properties of an amphibole called soretite, a hornblende which most nearly parallels the properties of the one under discussion. With $\alpha = 1.662$, $\beta = 1.676$, $\gamma = 1.685$, $\gamma - \alpha = .023$, and $Z \wedge c = 17°$, it has a higher birefringence and a much lower extinction angle. In the analysis the combined alkalies of soretite are 3.89 per cent. lower and ferrous iron is 3.43 per cent. higher.

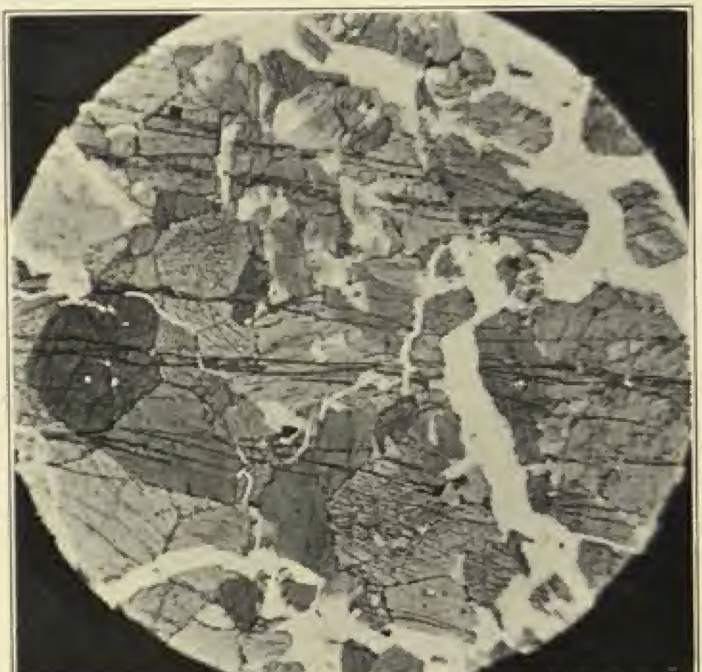
It is evident, then, that the amphibole under discussion is a hornblende in which a deficiency in iron has been compensated by a marked increase in the combined alkalies.

In seeking for an explanation of the peculiar composition of this hornblende the attention is at once directed to its mode of origin. It appears, in thin sections, as irregular aggregates in otherwise fresh pyroxenes, as compact hornblende with residual pyroxene, and finally as rare pleochroic crystals with basal 124 degree cleavage and octagonal pyroxene outlines [see Plate XI (*C*)]. The greater part of it is a compact hornblende clearly secondary after pyroxene. There is no way of isolating sufficient pyroxene from the rock itself, nearly completely altered as it is, but the vestiges which remain and the pyroxene in the endomorphic rim of the rock are much the same as to color, cleavage, and extinction as the crystalline pyroxene on the contact.

The following analysis of the pyroxene from the contact was made by Professor Phillips:

SiO_2	= 50.01	MnO	= 0.29
TiO_2	= 0.21	CaO	= 19.97
Al_2O_3	= 3.02	MgO	= 9.03
Fe_2O_3	= 4.80	Na_2O	= 2.68
FeO	= 9.89	K_2O	= 0.52
			100.42

[14] *Op. cit.*, p. 187.



C. Amphibole with 1,240 cleavage and remnant of pyroxene outline C-8-a. Ordinary light, × 20.

This is a diopside augite with a slightly higher percentage of soda than is usual. The optical properties are as follows:

$$\alpha = 1.698 \pm .003.$$
$$\beta = 1.710 \pm .005.$$
$$\gamma = 1.728 \pm .003.$$

$\gamma - \alpha = 0.030.$ Opt. (+), Non Pleochroic, $Z \wedge c = 44°$.

Evidently a solution rich in alkalies invaded the rock from within at some time during the formation of the contact metamorphic minerals, but after the pyroxene had crystallized. The felspars formed during this period are richer in both soda and potash than those in the body of the rock. The felspar of the endomorphic rock is mostly a sodic plagioclase, as is that of the intrusive proper, and contains a very little microcline. The felspar on the contact is microcline and albite with some microperthite. Some of this is apparently intergrown with pyroxene, but all the well-developed crystals are superimposed upon the pyroxene and appear to be younger. It is believed that the pyroxene crystallized before the felspar, though the two overlapped to some extent, and that the solutions of slightly later date which started the alteration of the pyroxene caused the formation of the alkalic felspars of the contact as well. The percentages of the alkalies in the two are relatively very different, however. Potash predominates in the perthitic intergrowths by two and one half to one, while soda is twice as plentiful as potash in the amphibole. The per cent. of the alkalies in the microperthite is as follows: $K_2O = 6.69$; $Na_2O = 2.73$.

The great variation of the completeness of the alteration of the pyroxene to hornblende must be due to a slight variation in its composition. Eskola [15] says: "It has been tacitly assumed that the pyroxenes by metamorphism most likely would be converted into amphiboles. From the view of the facies-conception this statement must be much restricted, and we may say, that uralitization takes place when pyroxene bearing rocks are brought under the conditions of the amphibolite-facies. . . . But even in the rocks of amphibolite-facies the diopside may be a stable constituent, viz., in those rocks in which

[15] "The Mineral Facies of Rocks," *Norsk Geologisk Tidsskrift*, Kristiania, 1920.

femic lime is present in excess over the hornblende ratio (in the simplest case CaO:(Mg, Fe) O::1:3). We may, in such a rock, find diopside seemingly in process of alteration to hornblende, and yet the diopside is not an unstable mineral. It is only unstable in the presence of an excess of magnesia, and in the case supposed the alteration had gone so far as possible at the composition given, and the rock had arrived at an equilibrium." The ratio of CaO to (Mg,Fe)O in this pyroxene is about one to one. Presumably the alteration went as far as it could under the then existing conditions. From the completeness of the alteration in the body of the rock it must be supposed that the ratio was different, namely, that (Mg,Fe)O content was relatively much greater. It is quite in line with the probability, judging from the development of an endomorphic contact zone, that the per cent. of lime in the border pyroxene is much greater than the per cent. of lime in the body of the rock, owing to the absorption of lime from the limestone.

Apatite occurs in the body of the rock as minute euhedral crystals and also as much later, large, irregular, anhedral masses.

The titanite is almost wholly anhedral and the individuals are large.

The felspar of the rock is nearly all an alkalic plagioclase ranging between oligoclase-albite and andesine. Specks isolated from the rock were determined as follows:

Oligoclase	$\alpha = 1.538 \pm .003$.
	$\gamma = 1.547 \pm .003$.
Andesine	$\alpha = 1.546 \pm .003$.
	$\gamma = 1.551 \pm .003$.

A good deal of the felspar is well twinned, but much has little or no sign of twinning even under the high power objective and is remarkably clear. Determinations of the felspar on the contact surface were as follows:

Microcline	$\alpha = 1.521 \pm .003$.
	$\gamma = 1.529 \pm .003$.
Oligoclase-albite	$\alpha = 1.533 \pm .003$.
	$\gamma = 1.544 \pm .003$.

Most of the readings for the sodic member showed it to be more nearly albite. Some of the felspar contains small, euhedral crystals of phlogopite.

Owing to the obscurity of the field relations this intrusive must be here regarded as an isolated fact. When the geology of the area is completed it is hoped that it will find its way into the intrusive sequence, but, for the present, it must be considered as a pyroxene diorite older than the porphyritic granite.

69–C–6–a. A large scale development of felspar, titanite, pyroxene, apatite, and scapolite crystals occurs disseminated along the contact between the intrusive described above and the limestone, in irregular pockets separated by relatively barren zones. The most noticeable exposure is on a face measuring 12 feet by 30 feet. This is at the southern end of the intrusive. The limestone has split away from the contact, thus exposing it, and the crystals form an intricate mesh on the slightly overhanging wall. Plate XII (*A*).

Blue-green to yellow-green apatite from one quarter of an inch to six inches in length and one inch in diameter; stumpy, dark green diopside-augites three or four inches long and two inches thick, with rectagonal and octagonal cross-sections; badly weathered, large felspar crystals, and small well-preserved ones showing the dome, prism, and pinacoids; poorly preserved, massive, silky gray scapolite; granular and minutely crystallized titanite; and interstitial pink calcite all occur abundantly, with the first two greatly predominating. The pyroxene and the felspar have been described under the rock minerals.

The scapolite is a wernerite very near to meionite. It has a high birefringence and the following indices: $\omega = 1.572 \pm .003$, $\epsilon = 1.549 \pm .003$, $\omega - \epsilon = .023$.

69–C–6–b. Following north along the contact this regular development of minerals gives way to pockets of pyroxene, felspar, and titanite, with minor wernerite. There are several of these and there is one pocket of solid apatite. These minerals cut the diorite irregularly and form veins running a short distance into it.

Just north of C–6–b, along the strike, there is a second small knob of diorite at the edge of which a tourmaline pegmatite dike occurs, and in the center of the open field directly east of that locality there

is an intricate mixture of limestone, pegmatite, and diorite. In the first case the pegmatite has done nothing but introduce some tourmaline and mica. The same irregular pyroxene-felspar contact is developed in pockets running several feet back from the contact which is underground. In the second case it is impossible to extricate the one from the other.

69–C–7. On the northwest end of the second locality mentioned in C–6–b there is a mica-bearing pegmatite dike cutting across the limestone. The east contact between the diorite and the limestone is hidden, but there are angular blocks composed of pyroxene and felspar along the surface. They measure as much as three feet by two feet and mark a thick contact zone. Quartz veins have penetrated the contact rock along the strike and have caused the formation of mica along their borders. These are evidently of a later date and have had no part in the formation of the pyroxene and the felspar crystals.

The limestone immediately to the south of locality C–6–a is coarsely crystalline and contains a very little graphite and occasional small lenses of pegmatite. The limestones of the whole region, as well as the intrusives and the contacts, are cut by many acid dikes. Thirty feet across the limestone valley from the mineral-covered surface C–6–a there is a rock composed of light green pleochroic hornblende and brown mica, both drawn out into lines, generally untwinned felspar, granulated quartz, magnetite, and euhedral apatite. This looks like a quartz-mica schist in thin section, but in the field it is seen to be an injection gneiss formed by the intrusion of acid material into the diorite.

Localities C–6–a and C–6–b are the only ones in this immediate vicinity entirely free from pegmatite intrusives, though it is at these places that the best minerals are formed. The contact at C–6–D is cut by a pegmatite dike, which does not affect the contact, but merely adds mica, and that at C–7 shows quartz veins of later age than the contact minerals.

These circumstances make it impossible to seek the origin of the contact minerals in any relation to the acid intrusives.

The facts that the diorite has suffered endomorphism (see Plate

A. Mesh of crystals on surface of diorite at Rossie, 69-C-6-a.

B. Diorite cliff at C-8, Rossie.

6 (*A*)), that the minerals occur along its contact and grade into it, and, finally, that the same minerals, with minor variations, form the rock and the contact, make it evident that the mineralized area is due to the metamorphosing action of the diorite and its vapors on the limestone.

The greater part of the contact is barren of minerals and here, as before, there is no variation of composition in either the limestone or the intrusive capable of accounting for such a variation in the formation of minerals. The magmatic solutions appear to have penetrated the whole mass of the diorite, so that here, again, as in the granite contacts, the localization of contact action is due to the local presence of channels for the escape of carbon dioxide. The limestone is stable under metamorphic conditions and a vigorous reaction must take place between the two rocks in order that new minerals may form. Any inherent weakness in the limestone or any channel caused by intrusion will be the locus for the collection of mineralizers and the escape of carbon dioxide. Magmatic solutions containing water vapor, silica, hydrochloric, phosphoric, and titanic acids, soda, and probably potash and alumina, will enter the limestone and react with lime and magnesia, or among themselves, or crystallize by cooling. Some lime and magnesia will pass off along with carbon dioxide and some will enter the intrusive and enter into the composition of lime-magnesia silicates.

More light is shed upon the relations of the pegmatite and the contact zones by another exposure of diorite one hundred yards north of C–6–a and west across a small valley. At this locality, C–8, see Plate XII (*B*), the contacts with the intrusive are exposed on all sides, though not everywhere continuously. A fifteen-foot cliff facing southeast shows a coarse diorite with a very narrow zone of coccolite surrounded by coarse, pink calcite which grades into white calcite four inches from the contact. Most of the surface of the intrusive is irregularly covered with quartz and a pink to white felspar which seems to lie between the intrusive and the limestone. Toward the north end there is a great development of black tourmaline.

These quartz-tourmaline-felspar veins are continuations of pegmatite dikes which intersect both the limestone and the intrusive as

well as the narrow coccolite zone. The intrusive has the same composition as at C–6–a, with the addition of slight amounts of wernerite and a little quartz, but no conspicuous mineralized zones are to be found. If the pegmatite were responsible for the minerals, it would seem that here where they are shown surrounding the diorite in a rough network and often lying between it and the limestone, as well as cutting both rocks, the mineral development should be greatest.

The absence of anything but endomorphic effects and a narrow coccolite zone, plus some nodules of tremolite distinctly connected with the pegmatite and at a distance from the diorite, is an argument against the formation of the minerals at the other localities by the granite pegmatites.

The Natural Bridge District.

The syenite in the immediate vicinity of Natural Bridge is the green augite syenite. A narrow, irregular belt of limestone runs through Natural Bridge and continues for two miles to the east and to the northeast. It is cut off to the north by a coarse, pegmatitic phase of the green augite syenite, but comes in again half a mile downstream. The augite syenite is composed predominantly of microperthite with a variable amount of augite which may form as much as half of the rock or may be nearly absent. Magnetite, titanite, and apatite are the common accessories and quartz varies from the rôle of a minor constituent to that of a major rock-forming mineral.

This rock is highly gneissoid. The quartz is very generally strained and granulated and the pyroxene and felspar are frequently fractured and optically strained. The pyroxene is altering to an aggregate of serpentine or chlorite, calcite, and hematite. The rock is intersected by dikes of hornblende syenite, coarse pegmatitic facies of pyroxene and felspar, and, toward its edges at least, by quartz microperthite dikes.

69–V–1. The locality lying downstream from the cement bridge just north of the natural bridge is on a point between two forks of the Indian River—one flowing above ground and the other under the

natural bridge. This point is composed of limestone cut by syenite-pegmatite dikes of felspar, titanite, fine-grained mica, and some pyroxene. Many of the smaller ones are largely felspar and pyroxene with considerable titanite. One pegmatite knob eight feet high and lying fifty feet west of the river, on the point, is composed solely of felspar and blue quartz.

These dikes are more or less intricately mixed with the limestone. Near the contact between the two, but generally in vugs in the syenite, there are frequent masses of crystallized diopside, microperthite, and titanite. The limestone doubtless extended into these cavities from above, but has long since been dissolved away. There are small, similar developments of silicates in the limestone itself. On the right bank of the river, directly opposite the last locality, a fairly regular contact between the dike and the limestone is exposed. The limestone is impregnated with pegmatitic material which surrounds coarsely crystalline calcite. Fifty feet downstream there is a finely banded, impure limestone which contains concentrations of graphite besides disseminated graphite, phlogopite, pyroxene, and felspar. A thin section cut from this rock showed a very pure limestone containing little graphite, but a considerable number of rounded pyroxene crystals.

The minerals:

Diopside	$\alpha = 1.673 \pm .003.$
	$\gamma = 1.702 \pm .003.$
Albite	$\alpha = 1.530 \pm .003.$
	$\gamma = 1.540 \pm .005.$
Microcline	$\alpha = 1.523 \pm .003.$
	$\gamma = 1.527 \pm .003.$

Microperthite—composed of microcline with intergrowths of albite or oligoclase.

69–V–2. At a point five hundred feet from the road, and the same distance south of the cement bridge, there is an isolated outcrop of a wollastonite, pyroxene, scapolite, schist. The relations of this outcrop to the surrounding rocks are entirely hidden. Under the microscope it shows no relic of its former self.

The minerals:

Wollastonite	white, silky.	
	$\alpha = 1.620 \pm .003$.	Extinction parallel.
	$\gamma = 1.634 \pm .003$.	$\gamma - \alpha = .013$.
Wernerite	$\omega = 1.578 \pm .003$.	Extinction parallel.
	$\epsilon = 1.555 \pm .003$.	$\omega - \epsilon = .023$.
Diopside	$\gamma = 1.697 \pm .003$.	The birefringence is high.

69–V–3–d. Downstream from V–1, on the left bank of the Indian River, two hundred feet above the dam and one hundred fifty feet west from the bank, there is an isolated exposure of bright green pyroxene in a white, sugary meionite which holds small reddish specks of titanite. This rock can not be related to its surroundings, but its composition suggests that it is a thoroughly altered limestone. The minerals:

Meionite	$\omega = 1.588 \pm .003$.	
	$\epsilon = 1.556 \pm .003$.	$\omega - \epsilon = .032$.
Diopside-Augite ...	$\alpha = 1.698 \pm .003$.	
	$\gamma = 1.725 \pm .003$.	$\gamma - \alpha = .027$.

69–V–4. A little more than half a mile downstream from V–2, to the east of the road on the right bank of the river, there is an old quarry in a pure white limestone. The nearest exposure of igneous rock is a syenite lying two hundred feet northwest of the north face of the quarry.

The marble here is very pure, with rare flakes of graphite and rounded pyroxenes, including shreds of calcite. A one- to two-foot band of brown weathering, dolomitic limestone passes through the north face of the quarry. This holds a little granular quartz, some much weathered diopside, and flakes of graphite, but is otherwise a pure magnesian limestone. This band contains a vein of dark, smoky, almost purplish calcite. The marble next to the brown band is pure white and holds the following minerals: green, serpentinized diopside, variable in hardness. Under the microscope this grades from a clear, colorless, very low birefracting mineral which gives a preponderance of isotropic sections and whose maximum and mini-

mum indices are 1.554 ± .003 and 1.540 ± .003, though no individual fragment gives so high a birefringence, to a comparatively fresh pyroxene with a birefringence of .027. Even the indices of this latter are low and it has all undergone some alteration. Thick pieces of the first variety show a dark blue, mat-like texture under crossed nickels.

Blue, beautifully formed octahedra of magnesia spinel. These are generally very small, with sides averaging about one eighth of an inch in length, but an occasional one shows a side one half of an inch long.

Brownish-pink diopside; and a reddish-brown fibrous wollastonite.

A number of loose boulders at the north side of the open end of the quarry contain more pink diopside and a deep reddish-brown wollastonite which simulates the dodecahedral crystallization of garnet.

In the west face of the quarry there is an irregularly developed, greenish-gray rock projecting through the limestone. This is a thoroughly altered rock which, both in the field and under the microscope, gives the impression of being an altered limestone layer. It contains pyrrhotite, residual pyroxenes which are pretty thoroughly chloritized, a little quartz, apatite, and phlogopite. Under the microscope one third of the rock is composed of good-sized, irregular crystals of a fibrous, brilliantly polarizing, altered mineral which appears to have parallel extinction. The fibrous character is frequently so well developed that aggregate polarization occurs. The remainder of the rock is a brownish, closely woven mat surrounding small units of pyroxene and of the brilliantly polarizing mineral. This resolves into a dark, serpentinous groundmass with magnetite and calcite. Some of this calcite, along with serpentine and magnetite, must doubtless be the result of the alteration of diopside, but more must be primary, as there is far too much of it for it all to have the first named origin. The highly polarizing mineral suggests scapolite, but there is no way to make sure. The rock then appears to be a serpentinized band of metamorphosed limestone containing originally pyroxene, scapolite, and a very little quartz, apatite, and mica.

These disseminated silicates so far from the intrusive are strange

in this region. The syenite may lie nearer in a vertical than in a horizontal direction, but at any rate its effects are felt at some distance out in the limestone. The white marble contains very rare grains of mica and graphite. Its content of lime is 54.47 per cent.; that of magnesia is only 1.13 per cent.

The minerals are scattered in such a manner that the low percentage of magnesia in the limestone seems sufficient to supply all of that oxide required. Lime, of course, is plentiful. With the exception of the spinel and possibly the scapolite of the serpentinized layer the minerals are non-aluminous, but these require some slight addition of alumina, and scapolite also requires chlorine. Beyond this the only requirement of magmatic addition is silica.

There is no way to ascertain the origin of the magnesia which enters into the process of serpentinization or that which is present in the band of dolomite. The regular quality of that band precludes the possibility of its being an original phenomenon in a limestone which has been folded, disrupted, and recrystallized, and the magnesia is believed to represent an addition from magmatic sources.

The minerals:

Dolomite .....$\alpha = 1.675 \pm .003$. Effervesces with strong acid.

Pyroxene ....$\alpha = 1.647 \pm .003$. Soft, green, serpentinized.
$\gamma = 1.674 \pm .003$. $\gamma - \alpha = .027$.

Wollastonite ..brown.
$\alpha = 1.625 \pm .003$. Gelatinizes.
$\gamma = 1.641 \pm .003$. $\gamma - \alpha = .016$, $Z \wedge c = 27°$.

Diopside .....pinkish. $\alpha = 1.670 \pm .003$.
$\gamma = 1.701 \pm .003$. $\gamma - \alpha = .031$.

Spinel ....blue. $\eta = 1.718 \pm .003$.

69–W–5. One mile east of Natural Bridge and north of Blanchard Creek, between two old limestone quarries and the road, there is a blasted pit on the syenite-limestone contact. So much excavating has been done here that the shape of the contact mass is obscure, but as seen at present the minerals are best developed immediately at the contact and in tongues projecting into the syenite.

The chief minerals developed are green diopside and titanite; also

a well-crystallized, light-green scapolite, microperthite, wollastonite, coarsely crystalline calcite, small, light purplish diopsides, and disseminated phlogopite.

Two hand specimens of the immediate contact were obtained. These show well-crystallized, light-green meionite and some dark-green pyroxene and titanite forming a bridge between the two rocks. They grade rather gradually into the syenite, but cease abruptly on the limestone side. The limestone for some distance from the contact is thoroughly impregnated with small meionite and diopside crystals. The greater part of the contact, however, is nowhere nearly so sharp as that. A massive pyroxene rock with coarse white calcite and granular titanite, with an occasional crystal an inch in cross-section, and fine, light, pink-brown diopside, intervene between the limestone and the intrusive. There is considerable fine-grained phlogopite distributed throughout all the contact material. Macroscopically the syenite itself is an aggregate of felspar and pyroxene with minor quartz and titanite. The pyroxene and titanite increase greatly in amount as the pyroxene-titanite contact rock is approached. So great, in fact, are the endomorphic effects that it is hard to separate the two rocks. A slide cut from a specimen three feet back from the contact showed predominant microperthite, light-green pyroxene with a low extinction angle, titanite, granular quartz, and sodic plagioclase, with apatite and pyrrhotite as minor constituents. The microperthite contains minute veins and specks of calcite. This coupled with the diopsidic character of the pyroxene indicates that the effect of the interaction with limestone penetrated at least that far into the syenite.

Where the contact material is predominantly meionite the syenite suffers no such a change. No sharp division as to location can be drawn between the two types.

The minerals are all intergrown and approximately of the same age, though titanite appears to have formed before meionite, as it occasionally occurs as inclusions within the latter.

The minerals:

Meionite ....green.

$\omega = 1.584 \pm .003.$

$\epsilon = 1.552 \pm .003.$ $\omega - \epsilon = .032.$ Opt. (—).

Parallel ext.

Felspar ...... microperthite-microcline. $\alpha = 1.531 \pm .003.$
$\gamma = 1.521 \pm .003.$

plagioclase.

Pyroxene .... dark green.

$\alpha = 1.677 \pm .003.$ $\gamma - \alpha = .025.$
$\gamma = 1.702 \pm .003.$ $Z \wedge c = 43°.$
pinkish. Diopside.
$\alpha = 1.677 \pm .003$ $\gamma - \alpha = .025.$
$\gamma = 1.702 \pm .003.$ $Z \wedge c = 41°.$

Wollastonite .. $\alpha = 1.619 \pm .003.$ Extinction generally parallel.
$\gamma = 1.631 \pm .003.$ May be up to 5.
$\gamma - \alpha = .012.$

69–W–6. One quarter of a mile farther west, through the fields, parallel to the road, on a southeast slope, there is an irregular exposure of a contact rock over one hundred yards long. The limestone and the syenite are not shown in actual contact here, but one glance suggests that it is a linear development of a contact similar to that at W–5. It is composed of a coarsely crystalline aggregate of felspar and pyroxene with granular titanite and makes a striking green and white rock with here and there a mat of pinkish-brown diopside. The limestone is impregnated with the same silicates and they are also frequently gathered into nodules. The coarse-grained, white limestone is very pure, but there are many fine-grained bands which are full of diopside and titanite. A zone of clear blue and green calcite parallels the contact about one hundred yards away from it.

The actual relations in the field are obscured by sod and soil, but it is clear that this mineral zone lies along the contact, the minerals being due to a concentration of magmatic agents along the border of the intrusive. These caused a coarse crystallization immediately at the contact and a fine development of the same minerals in bands at a greater distance.

The minerals:

Felspar-microperthite-microcline.

albite. $\alpha = 1.531 \pm .003.$
$\gamma = 1.539 \pm .003.$

Titanite.

Diopside—pinkish-brown. $\alpha = 1.673 \pm .003.$
$\gamma = 1.700 \pm .003.$ $\gamma - \alpha = .027.$

Diopside-augite—dark green.

$\alpha = 1.698 \pm .003.$ (Analysis on p. 159.)

$\gamma = 1.710 \pm .003.$ $\gamma - \alpha = .012.$

Directly south of W–5, toward the railroad and Blanchard Creek, there are two old quarries in the limestone. The predominant marble is a gray one which effervesces strongly in dilute hydrochloric acid. Besides this there are pink, white, and brown bands which are harder and show little or no effervescence. The brown bands generally lie above and below, or next to a visible fissure in the rock, and are believed to be due to weathering of the dolomitic content of the white bands. Besides these variations in the magnesia content the limestone contains lenses and knots of quartz, felspar, and diopside very similar to those in immediate relation to the contact at W–6. There is a syenite mass two hundred feet away to the north. Five hundred yards to the northeast there is another small abandoned limestone pit. The rock here is very white, but contains a far greater amount of impurities in the form of phlogopite, some serpentinized diopside, and small dikes and nodules of quartz and felspar. These latter are clearly of pegmatitic origin and, as the syenite lies only twenty feet farther to the northeast, the increase in siliceous impurities in this pit appears to be directly attributable to its presence. This suggests that the irregular nodular impurities in the other pit have the same origin.

Summing up this region of syenite-limestone contacts, we find that the minerals developed are less in number than was found to be the case in the granite area. Green and pinkish-brown diopside, white and red-brown wollastonite, titanite, meionite, wernerite, microperthite, quartz, and blue spinel are all that were found. To these must be added zircon, reported from these localities by Dana and Nims, and gieseckite, a pseudomorph after nephelite, formerly found near Natural Bridge. Chondrodite, tourmaline, and amphibole are completely lacking. Apatite was found in one place only and then in very minor amounts.

The development of minerals is, with a few exceptions, concentrated along the border of the intrusive and in the immediately adjacent limestone. Titanite, felspar, and pyroxene are the most abundant contact minerals. The titanite is the same as that in the in-

trusive. Pyroxene becomes diopsidic at the contacts due to the absorption of lime. The felspar of the contacts is a microperthite composed of microcline and albite or oligoclase-albite. Apatite has a considerable development in the intrusive itself, but does not occur as a contact mineral except in the one altered band in the quarry V–4.

The widespread dissemination of quartz and felspar of pegmatitic origin, so noticeable in the granite area, is lacking here. The great numbers of pegmatite dikes with which the quartz-tourmaline dikes and veins are associated are also absent. On the other hand, there is a coarsening of the intrusive along the contact, a tendency toward rather large and regular reaction zones between the intrusive and the limestone, prominent endomorphic effects, occasional disseminations of silicates at a distance from the syenite, a few big dikes of quartz and felspar in the limestone, without visible contact effects, and many small pyroxene and felspar dikes which are apparently confined to the intrusives.

This would seem to result from the intrusion of a magma fairly poor in mineralizers into a deep-seated mass of limestone. The marble was too pure and stable under metamorphic conditions to suffer a general alteration. Highly heated vapors, mostly water-bearing silica, hydrochloric and titanic acids, some soda and potash, and, locally at least, some magnesia, entered the limestone. This occurred probably only locally where shattering accompanying intrusion had locally lowered pressures, opened channels, and allowed free escape to carbon dioxide. The added material reacted with lime and magnesia and any slight impurities which may have been present. In a like manner some of the lime and magnesia passed into the intrusive to mingle with its magmatic constituents to form the endomorphic zone. Very locally there must have been zones of extensive interchange between the limestone and the syenite.

The minerals are all intergrown and belong to one period which may have extended through considerable time.

The heated condition of the limestone, buried to considerable depth, and the presence of active gaseous solutions, favored the formation of large crystals.

SUMMARY OF THE MINERALS.

The mineral groups represented in this area are few and fairly constant. Minor variations are found in all of them from place to place and even in the same locality.

The Micas: No attempt was made to differentiate the micas which occur so widely in this area. Dana [16] says: "(Phlogopite is) a magnesia mica near biotite, but containing little iron. Potassium is prominent as in all the micas, and in most cases fluorine. While phlogopite can not be sharply separated from biotite, its character and method of occurrence are so far constant and peculiar that it is most naturally placed by itself, while perhaps not deserving the rank of an independent species." Again: "The phlogopites are quite liable to change, loosing their elasticity, becoming pearly in lustre, with often brownish spots as if from the hydration of the oxides of iron."

It was found to be impossible to distinguish definitely between phlogopite and biotite by optical means or by the color, and as analyses of the micas of this region listed in Dana and in Iddings [17] place them as phlogopites, it is considered best to accept Dana's general classification.

Phlogopite is typically lower in ferrous iron and higher in magnesia than biotite, but no sharp distinction can be made here any more than in the optical properties.

As a rule the micas of this region are bronze or reddish brown, but deep brown, nearly black ones are not hard to find. They all frequently alter to a white, pearly lustred mica and lose their flexibility.

The Pyroxenes: The question of the pyroxenes is also a complicated one. So many factors enter into the composition of these minerals that optical tests alone are not always sufficient to determine the exact member of the series. As the indices of refraction of a pyroxene increase from those characteristic of diopside there comes a point where it is impossible to separate the diopside-augite from the diopside-hedenbergite series. The value of the extinction angle rises for both series as well, so that recourse must be had to chemical analysis.

[16] "A System of Mineralogy," pp. 633-637.

[17] "Rock Minerals," by J. P. Iddings.

The pyroxenes in the limestones and in the contact zones have, with few exceptions, been regarded as diopsides. Those associated with the granite-limestone contacts are light green to white through hydration. They have an average value for γ of about 1.699, with 1.715 as the highest. The extinction angle is between 37° and 40°. These are clearly diopsides low in both iron and alumina.

In 1896 Heinrich Ries [18] published a paper on the monoclinic pyroxenes of New York State in which he discussed the augites and diopsides of the Adirondack region as a whole. He draws an arbitrary distinction between the two according to the percentage of alumina. All pyroxenes with three per cent. and over of alumina he calls augites, while all with less than three per cent. he calls diopsides.

Ries places several pyroxenes in the granite area under augite, but in none of these cases are analyses or optical properties given. He apparently based his distinction on color, and the localities, described as " one mile southeast of Gouverneur," etc., are too indefinite to allow of any checking of his descriptions against the new material collected.

The following two analyses were published by Ries along with optical determinations. Only the indices of refraction are given here. These are both from the granite area and are given as diopsides.

DeKalb.		*Russel green, glassy crystals.*
54.86	SiO_2	54.94
1.30	FeO	1.29
24.13	CaO	25.38
18.14	MgO	17.60
0.75	Al_2O_3	2.42
0.35	Alks.	0.28
0.10	Ign.	
99.63		101.91
$\alpha = 1.667$		$\alpha = 1.662$
$\beta = 1.674$		$\beta = 1.671$
$\gamma = 1.696$		$\gamma = 1.694$

He also reports diopside as from Edwards, Macomb, Pierrepont, and Russel, but gives no analyses.

[18] " The Monoclinic Pyroxenes of New York State," Heinrich Ries, Contributions from the Mineralogical Department of Columbia University, Vol. VI., No. VI., 1896.

The pyroxenes associated with the syenite have an average extinction angle of from 41° to 44°, but their indices of refraction average only very slightly higher than those of the granite area. The greater part have a value for γ lying between 1.699 and 1.702. The two following analyses are taken from the same paper as the above.

Pitcairn.		*Ashmore Farm* (Natural Bridge).
54.57	SiO_2	53.97
1.30	FeO	8.63
21.42	CaO	23.96
18.56	MgO	17.32
3.09	Al_2O_3	4.94
....	Fe_2O_3	0.50
0.40	Alks.	
0.15	Ign.	

No optical properties are given with these two analyses, but they show the higher alumina in the pyroxenes of this region than in those of the granite area. The following two partial analyses give the percentages of iron and alumina in the pyroxenes occurring in two of the important contact areas of this region.

W–6.	*W–5–d.*
$TiO_2 = 0.24$	$TiO_2 = 0.16$
$Fe_2O_3 = 4.32$	$Al_2O_3 = 1.68$
$Al_2O_3 = 3.31$	$Fe_2O_3 = 2.40$
$FeO = 6.10$	$FeO = 5.43$
$MnO = 0.10$	

W–6 is darker and has higher indices, but a lower birefringency, than W–5–d. For W–6, $\alpha = 1.698 \pm .003$, $\gamma = 1.710 \pm .003$. For W–5–d, $\alpha = 1.677 \pm .003$, $\gamma = 1.702 \pm .003$.

The per cent. of Al_2O_3 in W–6 is above the arbitrary value established by Ries for distinguishing diopside from augite. Total iron is not very high in either one. Owing to the fact that the pyroxenes of this whole region grade from more or less pure diopsides to pyroxenes with a notable percentage of alumina and iron, it is considered best here to call those near the dividing line, as W–6, diopside-augites rather than augites.

The Amphiboles: The amphiboles are not nearly so widely distributed as the pyroxenes. In the granite area twenty-one localities

are described which contain amphiboles. Of these eleven are tremolite and ten are hornblende. The tremolite is invariably white and silky and its greatest and least indices rarely vary much from 1.625 and 1.600. Its extinction angle averages about twenty degrees. The hornblende varies considerably in color. It is generally the dark, silky variety known as pargasite. The indices are variable and the extinction angle, exclusive of the Rossie hornblende, varies between seventeen and twenty-five degrees. The peculiar alkaline hornblende at Rossie has been previously described.

Tremolite does not exist in connection with the Rossie diorite and neither tremolite nor hornblende is found in the contact zones of the syenite around Natural Bridge. It is impossible to say from negative evidence that amphibole never occurs as a syenite-limestone contact mineral, but as neither Nims nor Dana mentions its presence at either Pitcairn or Diana—the two noted syenite contact localities—it is pretty definitely established as absent.

The rôle played by magmatic solutions is clearly displayed in this relation. The syenites are comparatively poor in mineralizers and aqueous vapor. Their contact effects are less widely distributed than those of the granite, and amphibole, a product of comparatively low temperature requiring the presence of heated aqueous solutions, is absent, whereas pyroxene, the higher temperature mineral, is abundant.

The diorite at Rossie was originally a pyroxene rock and the hornblende developed there is secondary.

The granite, rich in magmatic solutions and probably intruded at a lower temperature, developed great quantities of amphibole as well as pyroxene along its borders.

The Scapolites: The scapolites are very irregular in their occurrence. Nearly all of those represented fall within the limits of the two types, missonite and wernerite, as given by Iddings,[19] but they are often on the upper or lower limits of these types, on the line between meionite and wernerite or missonite and marialite. Some are true meionites or marialites.

[19] "Rock Minerals," by J. P. Iddings, p. 257.

Scapolite occurs in great profusion in the granite area as distinct crystals, but chiefly, along with diopside and phlogopite, as aggregates completely replacing limestone, or in nodules with phlogopite and tourmaline. Marialite and missonite predominate in the nodules, but meionite is occasionally present, and in one case meionite, wernerite, and missonite occur nearly juxtaposed.

It is impossible to explain this variation except in solutions containing variable amounts of soda and in the formation of scapolite over a long enough range of time to allow the different ones to be deposited from solutions of different concentration in almost the same place.

The scapolites found with the syenite and diorite are all high in the meionite component. Most of them are true meionites. This would seem to indicate a greater concentration of soda-bearing solutions with the more acid rocks. In the absence of a high concentration of soda the excess of lime from the limestone controls the formation and the calcium-scapolite meionite forms. The presence of sufficient chlorine in the solutions is shown by the large amounts of apatite and chondrodite associated with the granite intrusives, and the apatite in the syenite and diorite.

J. Stanfield [20] explains the occurrence of a quartz-scapolite pegmatite in limestone as follows: "The pegmatite before consolidation assimilated a small amount of the limestone into which it intruded, and the assimilated lime gave rise to the lime bearing silicate scapolite, instead of orthoclase as in the rest of the vein. The chlorine required for the formation of the scapolites was an original constituent of the pegmatite. . . ." One case has been noted in this paper where a small dike of granite crystallized as scapolite and hornblende where it was intruded into limestone (see F–2). This was an endomorphic change in the granite magma in which assimilation of lime doubtless played the major part. Whenever a reaction involving the passage of magmatic material into limestone has taken place there is usually an accompanying zone of endomorphism. Sometimes apatite and tourmaline alone are formed, but more often diopside and frequently

[20] "New Mode of Occurrence of Scapolite," *The American Journal of Science*, Vol. XXXVIII., July, 1914.

tremolite crystallize in the intrusive. Lime freed by the driving off of carbon dioxide must then in part enter the igneous body.

J. Stanfield [21] considers the occurrence described by him as having an important bearing on the formation of rock types by assimilation. To quote: "It shows that in the case of even a small vein of pegmatite, such as is usually regarded as being intruded at low temperatures, speaking relatively of magmatic temperatures, the absorption of lime from a limestone country rock can take place, and that also, which is the important point, the absorbed lime may go toward the formation of lime silicates and not merely be redeposited as calcite. If assimilation may take place on the small scale represented in the occurrence (involving only a few cubic feet of magma), it is probable that on the larger batholithic scale it may play an important part in the change of the average composition of a large magma reservoir, and so become an important factor in the differentiation of rock types."

The occurrences described here are believed to show beyond question that lime and also magnesia are absorbed into the magma, and that they are redeposited as endomorphic lime-magnesia silicates, but the sum total of all such reactions where there is an endomorphic contact zone is very small. The region appears to be an ideal one for the development of assimilation because of deep burial and sustained high temperature, yet the rôle which it has played is so restricted and it is so completely lacking in the power to form unusual derivatives as to suggest rather the very local and limited power of assimilation to engender new rock types.

The Tourmaline: The tourmalines are all iron-magnesia tourmalines. Brown and black ones occur indiscriminately in limestone or in pegmatite. Only black is known to occur in the body of the granite away from any possible influence of the limestone. The percentage of ferrous iron determines the depth of color, and as the tourmaline becomes darker its indices of refraction rise, but the birefringence remains the same. The percentage of magnesia apparently has little effect on the color, though there is a general tendency for magnesia to rise as ferrous iron falls and vice versa. The Pierrepont black tourmaline retains as high as 11 per cent. MgO with 8 per

[21] *Op. cit.*, p. 40.

cent. FeO, while the DeKalb black has only 3.49 per cent. MgO with 12.55 per cent. FeO. The presence of so high a magnesia content in the Pierrepont tourmaline must be directly connected with the fact that it occurs partially in a gangue of dolomite.

The brown tourmalines are lower in iron and higher magnesia than most. The following analyses are from Dana's "A System of Mineralogy," pp. 554–555.

	SiO_2.	B_2O_3.	Al_2O_3.	FeO.	MgO.	CaO.	F.
Gouverneur Brown	38.85	8.35	31.32	1.14	14.89	1.60	
Gouverneur Brown	37.39	10.73	27.79	0.64	14.09	2.78	tr.
Pierrepont Black	36.64	9.55	27.18	9.08	10.13	2.01	
Pierrepont Black	35.61	10.16	25.29	8.19	11.07	3.31	0.27
DeKalb Black	37.07	9.70	31.86	12.55	3.49	—	0.31
DeKalb Colorless	36.88	10.58	28.87	0.52	14.53	3.70	0.50

The magnesia of the brown tourmalines in the dikes may be due to the absorption of limestone or it may be a magmatic addition. Certainly, though the average percentage of magnesia in the limestone is very low, especially in view of the greater chemical activity of magnesia than of lime, there is sufficient to be gathered by the ascending vapors and later deposited as tourmaline. The presence of zoned crystals, which must have crystallized by cooling, in limestone with a center of brown tourmaline and a rim of dark brown or black, shows that the magnesia was not picked up by the tourmaline in any reaction with limestone while crystallizing. If this magnesia was picked up from the limestone, it must have been acquired during the passage of the vapors along the channels through the limestone. The dolomite matrix at Pierrepont is so local that it can not be an original feature. On the contrary, its occurrence suggests that it is due to magnesia rich solutions accompanying the tourmaline.

Graphite: There are a number of papers discussing the origin of graphite in crystalline limestones, particularly in the Adirondacks, and it is not the writer's intention to enter into that controversy in this paper. However, graphite is so continuously present among the contact metamorphic minerals of the region that its mode of occurrence must be noted.

Graphite occurs as inclusions in all of the silicates, as flakes of

considerable size intercrystallized with the contact silicates in nodules, as linearly developed bands parallel to contacts, and as concentrations in and at the edge of pegmatite dikes and quartz veins. In the area about K–11 and K–12 it is frequently the only mineral that accompanies quartz and it frequently imparts a dark, dirty aspect to the limestone.

It is evident, then, that whatever form the carbon may have had before the contact metamorphism took place, the intrusions have played a part in concentrating it. It is recognized that oxides of carbon are soluble in water and silicate solutions under pressure and, whether the carbon comes from the original carbonaceous matter in the limestone, from the breaking down of calcium carbonate, or in part from the magmatic solutions themselves, it will travel with those solutions and, upon cooling below about six hundred degrees centrigrade, it will crystallize out as graphite. It is possible, then, that much of the flake graphite, widely scattered in the crystalline limestone, owes its origin to the same solutions that caused the formation of phlogopite, diopside, tremolite, and later, quartz.

The Felspars: The characteristic felspar of the region is a microperthite. Microcline and albite occur singly and as intergrowths and make up the greater part of the microperthite. The indices of refraction of the felspars were used to separate them and, whenever possible, the components of the microperthite were determined.

In the granite area microcline and albite are found in equal quantity. Orthoclase and microperthite are about half as plentiful, and andesine is recorded twice, accompanied once by albite and once by microcline. Albite occurs wherever microperthite is found and the potassic component is either microcline or orthoclase. In one case orthoclase, microcline, microperthite, and albite occur together.

At Rossie the characteristic felspars in the contacts are microcline, albite-oligoclase, and microperthite; in the diorite itself, oligoclase-albite or andesine.

In the syenite microperthite is the predominant felspar with microcline and albite usually present. The felspars developed along the contacts are similar. No zoned felspars were found anywhere.

The general tendency for the felspar to occur as a contact mineral

in the syenite contacts and at Rossie is in sharp contrast with the granite area. Except for the microcline and albite accompanying quartz as a replacement of limestone, and occasional scattered felspar crystals in this rock, the felspar of the granite area is confined to the dikes and veins of pegmatite and to the granite.

H. L. Alling [22] concludes that pressure does not produce microcline from orthoclase, but that it initiates and accelerates the change. The preponderance of microcline over orthoclase in this area where some disturbance has taken place since the formation of the felspars is in accord with his conclusion. The prevalence of microperthite which, according to the same author, is due to "exsolution" from a metastable state, would seem to be normal in a region of initial high temperature and slow cooling under heavy cover. The completeness of the separation of the soda-lime component from the potash component should be controlled by time, but even more by the length of time during which a high temperature prevails.

Apatite: Apatite is one of the first minerals to crystallize in the syenite magma, but by far the greater part of its components pass over into the granite, which, as was stated in the summary of the geological history of the region, is believed to be a later member of the same intrusive sequence, and thence into its magmatic solutions. It crystallizes as an accessory in the granite and in both the endomorphic and exomorphic contact zones, rarely going far from the intrusive mass. It never occurs in the contact deposits formed by the syenite except in the altered band in the quarry V–4. In this case it was carried by solutions emanating from the syenite.

Titanite: Titanite, in its behavior, is almost the direct opposite of apatite. It crystallizes in the syenite and is abundant in the syenite contact zones. Some passes over into the granite magma and crystallizes in the granite or its dikes at or near the contact; but only in one case does it pass out into the limestone from the granite, as at K–5–b. Possibly the titanium needs an addition of lime from the limestone as well as the silica of the granite to form titanite.

Both apatite and titanite occur plentifully in the Rossie diorite and in its contact zones.

[22] "The Mineralography of the Felspars," Pt. 1, *The Journal of Geology*, Vol. XXIX., No. 3, p. 209.

Spinel and Chondrodite: These two minerals form the only constant association over the whole region. It is a common association which has been described many times. Spinel never occurs here without chondrodite or its alteration product serpentine, or both. Chondrodite, on the other hand, may occur without spinel. They are both magnesian minerals, but have not been found in the company of tourmaline.

Spinel has been formed artificially by several means, two of which require the presence of boracic acid. It is possible that spinel and the fluosilicate chondrodite might form here in the presence of boracic acid where considerable magnesia and hydrofluoric acid existed. When magnesia was lower chondrodite alone would form. Just what relation between magnesia and boracic acid or perhaps temperature-pressure conditions would bring about the formation of tourmaline instead is impossible to say.

Serpentine: Serpentine is found as an hydration product of chondrodite and diopside throughout the region.

Pyrrhotite: Pyrrhotite occurs as grains and small crystals scattered throughout the limestone at a few of the contacts and as an accompaniment of some of the quartz dikes, which are later than the pegmatites proper. It is a high temperature mineral and is the only sulphide found in these occurrences. Its presence here to the exclusion of pyrite, which may be formed under a variety of conditions, is another indication of the high temperature origin of the deposits.

Summary.

General.—(1) The region is one of Pre-Cambrian rocks. The oldest of these are the Grenville sediments. There is no known top or bottom to this series. The crystalline limestone in which the contact metamorphic minerals occur is a member of this formation.

(2) Subsequent to the deposition of the sediments there came a period of regional metamorphism.

(3) This was followed by at least two series of igneous intrusions.

a. Gabbro and granite.

b. Anorthosite-syenite-granite-gabbro.

These are all more or less metamorphosed.

(4) This was followed by a long period of erosion which left the surface substantially as it is today. The overlying paleozoic sedimentary capping has not yet been entirely removed.

(5) The contact and contact regional metamorphism of the limestone due to these intrusives has been superimposed upon the older regional metamorphism.

(6) This paper deals only with the scattered metamorphic effects of the syenite and granite of the later period along with those of a diorite of unknown affiliations.

(7) There are many miles of barren contact between the limestone and the intrusives.

(8) The contacts are of three kinds:

a. Narrow bands of thoroughly altered limestone.

b. Pockets at or near the contact and others far out in the limestone.

c. Disseminated minerals and nodular aggregates of minerals in certain areas of limestone.

Both of the first two are accompanied by considerable endomorphism.

(9) The development of metamorphism is patchy and irregular. There are no well-defined zones of metamorphism to study.

(10) The problem is one of linking a certain set of metamorphic phenomena to one intrusive or to a certain set of intrusives, of accurate description of the various local developments of minerals, and of the presenting of data bearing upon the relative value of recrystallization and of magmatic additions.

(11) Contact metamorphism is taken to include all those changes produced in the country rock by the intrusion of igneous magmas, whether by simple recrystallization due to heat and dilute vapors already in the rock, or to the introduction of magmatic substances, or both, as well as the endomorphic changes in the intrusive itself.

(12) Endomorphic effects are common. As a rule the contact zones developed along the junction between the intrusive and the limestone grade gradually into the intrusive, but end abruptly against the limestone.

(13) Evidence is given by amphibole and wollastonite that the minerals of the syenite contacts were formed at a higher temperature than those of the granite contacts.

The Granite Area.—(1) There is a multiplicity of detail, but underlying it a general similarity.

(2) There is a great deal of barren contact and all three forms of contact mentioned above occur.

(3) The metamorphic effects are mostly due to the pegmatites, the quartz veins, and their derivatives.

(4) The rare elements, so often characteristic of pegmatites, are lacking.

(5) Definite mineral associations are few and evidences of sequence of formation are lacking except in the case of the late development of quartz and felspar.

(6) The problem is to determine what brought about the formation of these minerals, their peculiar distribution, and their absence over such long sections of the contact.

(7) Differences in composition of the limestone and the intrusive are not competent to explain it.

(8) The limestone is too pure. It does vary slightly in magnesia and in silicate content. The amounts of the latter are hard to determine, as the contact metamorphism has fairly well hidden the effects of the former composition and of the original metamorphism.

(9) The limestone at the start of the contact metamorphism was coarsely crystalline, contained bands of quartz, and some disseminated phlogopite, diopside, tremolite, and carbonaceous matter.

(10) The presence of chondrodite and tourmaline among the disseminated minerals shows the activity of the mineralizers. Large quantities of these latter were squeezed out into the limestone.

(11) The localization of the contacts is caused by local fractures in the limestone due, in part, to the act of intrusion.

(12) Shattered zones along the contact give the completely altered bands. Crushed zones, at a distance from the intrusive, but connected by fractures, give the pockets at the contact and at some distance from it. Lastly, fractures running out into the limestone give the disseminated silicates and the pneumatolitic minerals. These are all doubtless connected with granite in depth.

(13) The following minerals occur in the contact zones: diopside, tremolite, hornblende, phlogopite, marialite, missonite, wernerite,

meionite, chondrodite, spinel, apatite, titanite, brown and black tourmaline, fluorite, quartz, graphite, and very rarely, microperthite. In the dikes: quartz, microcline, albite, microperthite, orthoclase, titanite, and apatite.

(14) These minerals show an abundance of vapors, probably dissolved in water, such as hydrochloric, hydrofluoric, and boric acids, along with silica, phosphorus, soda, and alumina, with some potash and magnesia.

(15) These vapors varied from time to time, although there is no proof of any progressive variation.

(16) Intergrowths of pyroxene and amphibole, the close proximity of different scapolites and brown and black tourmalines, prove the variation in composition of the solutions and necessitate their activity through a considerable period of time.

(17) Calcite forms the host for the silicate minerals and is frequently recrystallized with them.

(18) Last of all, quartz and felspar are deposited in the limestone by metasomatic replacement, in the form of long, narrow veins.

(19) At some time later these same minerals were strained and granulated, calcite was recrystallized and replaced quartz and felspar to some slight extent. This replacement also took place occasionally in the case of the silicates.

Rossie.—(1) The intrusive is a mica hornblende diorite. The hornblende is secondary, but the felspar is too alkalic for a gabbro. Therefore the rock must have been a pyroxene diorite. It is older than the porphyritic granite.

(2) The contact minerals occur on one large face and in local pockets. Endomorphic effects are marked. There is no metamorphism at any distance from the intrusive.

(3) Pyroxene, apatite, scapolite, and titanite are of one period. A later accession of alkaline solutions caused the alteration of the pyroxene to an alkali hornblende and brought about the formation of the alkaline felspars. These periods overlapped.

(4) The amount of the alteration of the pyroxene in certain localities is probably controlled by its composition.

(5) The character of the limestone and of the intrusive is far

too regular to account for the great irregularity of the contact effects.

(6) This localization of the contacts is controlled by fractures in the limestone probably caused by the act of intrusion.

(7) Magmatic additions consist of water vapor, silica, hydrochloric, titanic, and phosphoric acids, and later soda and potash with probably some alumina. Some lime and magnesia pass off with the carbon dioxide. The rest enters the rock and gives endomorphic zones.

(8) The granitic pegmatite and quartz dikes of this region do not affect the contact described.

Natural Bridge.—(1) The syenite is not accompanied by a great number of dikes such as are characteristic of the granite area. This results in giving fewer exposures of contacts.

(2) Some blue-quartz, felspar pegmatites occur. These have apparently no metamorphosing effect on the limestone. Pyroxene-felspar pegmatites occur in the intrusive, but do not pass out into the limestone.

(3) Contact deposits are in bands or in pockets nearly always at or very near to the actual contact between the limestone and the intrusive.

(4) Endomorphic effects are very well developed and are accompanied by a coarsening of the intrusive along the contact.

(5) Titanite, microperthite, diopside-augite, diopside, meionite, wernerite, apatite, wollastonite, spinel, and zircon are developed in this region.

(6) The syenite magma is not as rich in mineralizers as the granite magma. What mineralizers there are were concentrated along the borders and did not travel far out into the limestone. There are, however, a considerable number of disseminated minerals in the body of the limestone. These scattered metamorphic effects are only slight here in comparison with those of the granite area.

(7) Wollastonite is the only lime silicate in the region which is free from magnesia.

(8) The minerals all form irregular aggregates and show no definite order of succession.

(9) There is no later addition of quartz and felspar.

The Minerals.—(1) The micas are all classed as phlogopites following Dana's description of that mica.

(2) The pyroxenes are both diopsides and augites. Diopside is characteristic of the granite area, diopside-augite of the contact at Rossie, and both diopside and diopside-augite of the syenite area.

(3) The amphiboles are not so widely distributed as the pyroxenes. Tremolite and hornblende are about equally plentiful in the granite area. Tremolite is lacking at Rossie and both tremolite and hornblende are absent in the syenite area around Natural Bridge.

(4) The Scapolites. The granite area is marked by the presence of marialite and missonite. There is some wernerite and meionite. Meionite is characteristic of the other localities. This is probably to be explained by the greater concentration of soda in the magmatic solutions of the granite area. In their absence the lime scapolite forms. Scapolite may be formed locally in pegmatite by the assimilation of limestone. This plays no part here in the development of new rock types.

(5) Both brown and black tourmaline grow indiscriminately in limestone or in pegmatite. Only black has been seen in the granite far from the limestone. The per cent. of ferrous iron determines the color of the tourmaline. The indices of refraction rise with increasing darkness, but the birefringence remains the same. Magnesia does not much effect the color, though it has a tendency to increase as iron decreases and vice versa. All of the magnesia in the tourmaline does not seem to be due to absorption from the limestone. Some is probably magmatic. There is evidence of magmatic magnesia in the region.

(6) The Felspars. The commonest felspar for the whole region is microperthite. In the granite area microcline and albite are most frequent, with orthoclase and microperthite next in quantity. Andesine is reported twice. Felspar rarely occurs here as a contact mineral. In the syenite area microperthite is the commonest felspar, almost to the total exclusion of any other. It occurs very widely as a contact metamorphic mineral. At Rossie microcline and microperthite are about equally developed in the contact zone. Oligoclase-albite and andesine form the body of the felspar in the rock.

(7) Apatite is found in the syenite, the diorite, and the granite, and also as a contact mineral about the last two.

(8) Titanite is found in the syenite, the diorite, and the granite, and as a common contact mineral with the first two. It rarely occurs as a contact mineral with the granite and then only as an endomorphic development.

(9) Chondrodite and spinel form the only constant association in the whole region.

(10) Pyrrhotite occurs occasionally as a contact mineral with the granite and its accompanying quartz dikes. It is the only sulphide found in these mineral masses.

TABLE OF AVERAGE INDICES OF REFRACTION.

Diopside: $\alpha = 1.670$, $\gamma = 1.699$

Diopside-augite: Rossie $\alpha = 1.698$, $\gamma = 1.728$; Natural Bridge $\alpha = 1.698$, $\gamma = 1.725$ and 1.698, 1.710

Tremolite: $\alpha = 1.600$, $\gamma = 1.625$ and 1.606, 1.636

Hornblende: $\alpha = 1.620$, $\gamma = 1.642$ and 1.627, 1.650 and 1.638, 1.656; Rossie $\alpha = 1.660$, $\beta = 1.674$, $\gamma = 1.680$

Wollastonite: $\alpha = 1.620$, $\gamma = 1.634$ and 1.625, 1.641

Chondrodite: $\alpha = 1.600$, $\gamma = 1.627$ and 1.607, 1.636

Tourmaline: Black $\omega = 1.650$

Dark Brown $\omega = 1.643$, $\epsilon = 1.622$ and 1.640, 1.620

Light Brown $\omega = 1.637$, $\epsilon = 1.618$

Light Yellow $\omega = 1.634$, $\epsilon = 1.615$

Apatite: $\omega = 1.634$, $\epsilon = 1.631$ and 1.630, 1.628

Spinel: $\eta = 1.713$ and 1.710; Natural Bridge Blue $\eta = 1.718$

Felspars: Orthoclase $\alpha = 1.520$, $\gamma = 1.525$; Microcline $\alpha = 1.523$, $\gamma = 1.527$ and 1.521, 1.530

Albite $\alpha = 1.530$, $\gamma = 1.539$; Andesine $\alpha = 1.546$, $\gamma = 1.552$; Oligoclase $\alpha = 1.541$, $\gamma = 1.547$

Scapolite: Marialite	$\omega = 1.555$		
	$\epsilon = 1.541$		
Missonite	$\omega = 1.563$		
	$\epsilon = 1.547$		
Wernerite	$\omega = 1.577$	and	1.572
	$\epsilon = 1.549$		1.548
Meionite	$\omega = 1.588$		
	$\epsilon = 1.553$		

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THE CLINICAL SIGNIFICANCE OF THE HISTOLOGICAL LESIONS OF RHEUMATIC FEVER.

By HOMER F. SWIFT, M.D.

(Read April 20, 1923.)

Rheumatism, in the popular sense of the word, is a condition that directly interests the majority of mankind. Most of us suffer occasionally from pain or stiffness in the muscles or joints; and "rheumatism," when used to describe these ailments, has merely a symptomatic significance. Wiesel has recently stated that no less than 80 different pathological conditions have been included under the term. But gradually, as more exact knowledge of various diseases has been acquired, one after another of these numerous conditions has been placed in its proper nosological position. We now realize that inflammation of the joints or muscles is usually a symptom of some general disease. In fact, most specific bacterial infections have arthritis as one of their complications. In some, such as gonorrhea or tuberculosis, joint involvement is not uncommon; in others, such as typhoid fever or lobar pneumonia, it is rare. Marked general metabolic disturbance may also lead to arthritis; probably the most striking example of this is gout, a disease in which there is definite involvement of bone and a deposit of salts of uric acid in the tissues making up the joints. It is possible that other forms of arthritis are also due to faulty metabolism.

But the disease known today as rheumatic fever was generally regarded, until recent years, as having arthritis as its principal manifestation. Indeed, the term inflammatory rheumatism, or acute articular rheumatism, is sufficiently descriptive to indicate that historically, at least, attention was focused on the organs of locomotion. With the development of auscultatory methods and the application of statistical studies it soon became evident that chronic cardiac valvular disease was frequently preceded by acute arthritis. Endocarditis was then regarded as a complication or sequella of acute articular rheuma-

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tism; but gradually we are realizing that heart involvement is the most important part of the disease, and that the patient is often suffering from active visceral infection with little or no evidence of arthritis. This altered conception of the disease is reflected in changes from time to time in the names applied to it, viz., acute articular rheumatism, or acute inflammatory rheumatism, acute rheumatic fever, or better still, rheumatic fever; the last appellation is probably best because the infection not infrequently passes into a subacute or chronic form.

It is surprising that in spite of the great advance in the knowledge of the causation of most common infectious diseases we still must recognize our uncertainty of the etiologic agent in this infection. Certain contributing factors have been suggested, and non-hemolytic streptococci have been claimed by several authors to be the causative micro-organisms; but the failure to recover these streptococci from a majority of patients and the fact that the classical disease presented by man has not been reproduced by inoculating them into the lower animals has caused most students to hesitate before considering the question settled.

To obtain a better understanding of rheumatic fever we are, therefore, forced back to a continued bedside study of the patient, with newer instrumental methods to aid our senses, and to an examination of the various tissues that can be obtained from the subject during life and postmortem. By the correlation of the different facts so obtained we should arrive at a more exact knowledge of the life history of the disease.

The gross clinical manifestations of rheumatic arthritis are pain, tenderness, swelling, redness, and local heat diffusely distributed about the joint; an examination of the synovial fluid reveals many exudative cells—mostly polymorphonuclear leukocytes. Remarkable features of the acute arthritis are: (1) the tendency for the inflammation to migrate—"to jump"—from one joint to another without any apparent involvement of the intervening tissues; (2) the failure of the process to go on to suppuration; and (3) the rapid disappearance of the symptoms and signs of inflammation after the patient has taken such antipyretic drugs as certain derivatives of salicylic acid or of phenylcinchoninic acid.

In fatal cases, the longest recognized and most striking gross feature found postmortem is the appearance of rows of small bead-like excrescences along the free margins of the heart valves. On microscopic examination these verrucæ are seen to be made up of coagulated elements derived from the circulating blood; in other words, they are small globular thrombi deposited on the valvular endocardium at a place where the lining endothelium has disappeared. In older verrucæ there is also definite evidence of a tendency to healing; the verrucæ are covered with endothelium and invaded by organizing connective tissue. But even in the young lesions there is seen in the substance of the heart valve under the endocardium distinct evidence of inflammation not exudative but proliferative in nature. It is a moot point whether the destruction of the endothelium is primary or subsequent to an injury to the underlying tissue. Of this, however, we are certain—that characteristic lesions occur in the subendocardial region without primary injury to the endothelium. It is not difficult to conceive, therefore, of the primary injury of the valves occurring in their substance rather than on their surface. If edema and swelling are present in the valves to the same extent as about the joints, it is easy to think of these structures as being functionally faulty and to see the possibility of the swollen covering endothelium being broken by repeated impacts against an opposing valve leaflet.

When the pericardium is extensively inflamed there is often a widespread pouring out of sero-fibrinous exudate with a plastering together of the two layers of the pericardial sac. Upon first glance this seems an entirely different process than is found in other tissues; but the presence in the pericardium of focal lesions similar to Aschoff bodies—which shortly will be described—indicates that the essential or primary pathological process is similar to that found elsewhere, but that the gross appearance is altered by the peculiar anatomical structure of the pericardial sac, and the manner in which such large endothelial membranes respond to injury.

The most generally recognized specific histological lesion of rheumatic fever is the so-called Aschoff body, which is a submiliary nodule located in the myocardium usually in close relationship with small blood vessels. There is practically always a small central area of

necrosis surrounded by peculiar cells having vesicular nuclei and a cytoplasm that takes a granular red color when stained with methyl green and pyronin; usually many cells are present with multiple nuclei, forming a particular type of giant cell, different from that seen in tuberculosis.

Mixed with these Aschoff body cells are polymorphonuclear leukocytes and lymphocytes in various amounts, proportional to the acuteness of the general infection. Although the submiliary nodule is primarily in the interstitial tissue, the surrounding muscle fibers are often seen to be involved. Indeed, certain pathologists claim that the giant cells arise from the muscle fibers; although the majority of observers think that the cells forming the nodules are derived from the endothelium of the perivascular spaces and from the endothelial lining of the blood vessels.

Changes in the blood vessels are common; not infrequently one encounters partial or complete closing of the lumina with thrombi that have probably been formed as a result of injury to the vessel wall. The blood vessel may also be constricted in other ways. We have seen Aschoff bodies in the perivascular space push one segment of the wall against another. When two or more submiliary nodules are close together, but on different sides of a vessel, the edema, often present in the region of such foci, probably forms a constricting ring. Interference with the circulation must lead immediately to disturbed nutrition of the muscle tissue and of the impulse conducting fibers supplied by the involved blood vessels. Bedside study and electrocardiographic investigation in a series of our patients indicates that the myocardium or conduction system was disturbed in over 90 per cent. of the cases. While it is conceivable that these functional disturbances may have been merely toxic in origin, it seems more rational to conclude that there is a direct relationship between the histopathological lesions demonstrable postmorten, and the disturbed myocardial function found during life. The transitory nature of many of these cardiac disturbances is no argument against their being due to actual focal lesions; for evidence is constantly increasing that focal lesions are present about inflamed joints, even though clinical manifestations of arthritis are present only a few days.

It is important, on the other hand, to realize that active disease of the heart may be the only demonstrable evidence of a continuing rheumatic fever infection. Recently two fatal cases have been brought to our attention in which myocardial weakness was the sole clinical picture, and postmortem the only essential lesions were Aschoff bodies widely disseminated throughout the heart muscle. In several patients suffering from chronic cardiac disease we have observed relapse after relapse with pyrexia and the general features of recurring infection in which all of the symptoms and signs were referable to myocardial and endocardial involvement. Postmortem, these cases have shown widespread rheumatic myocarditis, along with endocarditis and pericarditis. These correlated clinical, physiological, and pathological studies are giving us a clearer conception of the chronic or relapsing nature of rheumatic fever.

For many years English clinicians have called attention to the frequent occurrence of fibroid nodules in the subcutaneous tissue of rheumatic children. Anatomically, they are found in the deep fascia over bony prominences and in tendon sheaths and tendons, and because of their superficial situation it is possible to remove them easily and thus to obtain a better idea of the pathological changes occurring during life. The essential histological picture is similar to that seen in the Aschoff body. There is tissue destruction varying in size from small submiliary areas to long strands of hyaline necrosis affecting connective tissue fibers; combined with necrosis are deposits of fibrin. In close relation to these destroyed foci are found numerous cells similar in appearance and staining reaction to the type cell found in Aschoff bodies; multinucleated cells are also present. In nodules it is not difficult to demonstrate these endothelioid cells arising from perivascular spaces as well as from the vascular endothelium. In fact, the participation of the blood vessels in the general response is one of the most marked features of the subcutaneous nodules. Many capillaries are seen in which the swollen endothelium has practically obliterated the lumen; in larger vessels the proliferation of the endothelium at times takes the form of a crescent-shaped mass of cells, appreciably narrowing the vessel. Still other small arteries are seen obliterated by thrombi; in others the media is involved; and surround-

ing many of the smaller vessels there can often be seen collections of endothelioid cells evidently compressing the walls.

A participation of fibroblasts arising from the connective tissue is easy to demonstrate. A few polymorphonuclear cells and lymphocytes invade the diseased tissue and foci of edema are demonstrable. While, grossly, these nodules vary in size from ½ mm. to 5 or 10 mm., it is evident upon microscopic examination that the larger nodules are composed of a conglomeration of submiliary nodules. The pathological unity of the myocardial and subcutaneous lesions is, therefore, easily comprehensible.

These subcutaneous nodules attract attention clinically only on account of their mechanical presence. They are usually painless because they are not in close apposition to nerves. Involving only connective tissue which has no important function except that of a supporting structure, they are not a local source of danger. Their chief significance is that they indicate a similar process going on in important organs, as the heart or brain.

The inflammation of the joints, a most outstanding feature from the patient's viewpoint, has been the least studied by histopathological methods. The transient nature of the arthritis, and the fact that patients rarely succumb to the acute disease, easily explains this apparent gap in our knowledge. Heart failure is practically always accountable for the death of these patients at a time when the arthritis has disappeared, and hence the chief attention of the pathologist has been directed to this organ.

Nevertheless, Fahr has found changes in the capsule of the knee of patients succumbing to rheumatic fever which he states are in every way comparable to the myocardial lesions. Cary Coombs makes a similar statement concerning the shoulder joint of one patient. Lately, we have excised small pieces of the capsule of the knee or ankle of patients during the acute stages of rheumatic arthritis, and found focal lesions of the synovia, focal necrosis of the capsule, thrombosis of the smaller arteries, and endothelial and perivascular reactions quite comparable with changes found in the heart and in subcutaneous nodules. The presence of many small nerves in the joint capsule and surrounding ligaments easily explains the great

pain occurring in rheumatic arthritis. The additional finding of distinct histological lesions in the joint capsule of a patient who was fully under the influence of neocinchopen, and from whom all clinical signs of arthritis had disappeared, shows that the essential rheumatic process goes on in spite of these antisymptomatic drugs.

The relation of St. Vitus' dance, or chorea minor, to rheumatic fever has been discussed for many years. It has been known that valvular heart disease and chorea were frequently concomitant; also that arthritis and chorea occurred together. The relatively few studies of the brains of chorea patients indicate that the chief lesion is vascular in origin. Thrombi, endothelial proliferation, and perivascular collections of round cells together with small focal changes in the nervous tissue contiguous to these vessel lesions have been described. The very small amount of connective tissue in the parenchyma of the brain, and the fact that the response of the central nervous system to injury is normally a neuroglia proliferation, would naturally cause a different histological picture in the brain than would be seen elsewhere. The finding, however, of typical Aschoff bodies in the hearts of patients dying from chorea, and the demonstration of subcutaneous fibroid nodules in others who have recovered, all support the viewpoint that the lesions in the various organs are all evidence of tissue response to a common causative agent—the virus of rheumatic fever.

With this conception of the essential pathology of rheumatic fever—viz., focal nodules with edema in the contiguous tissues during the acute stages combined with lesions of blood vessels—it is not difficult to reconcile the manifold and apparently unrelated manifestations of the disease. It is apparent that the type of response is an effort on the part of the body to limit the activity of the virus; a type that in many ways reminds us of the focal lesions of tuberculosis or syphilis. The edema, redness, and local heat seen about the joints with acute arthritis are evidence of an intense tissue response, and give us the impression that exudation is the most marked feature. These gross clinical signs, however, disappear quickly—both spontaneously and following the exhibition of certain drugs. But small disseminated lesions of a focal character are evidently present in the periarticular tissue and synovia much the same as in other organs,

and are doubtless slower in undergoing complete resolution than the rapid recession of clinical symptoms would indicate. The pain and tenderness of the acute arthritis is doubtless due to the implication of numerous nerves in the acute exudative process. With the disappearance of extensive edema these symptoms usually disappear; but not infrequently one encounters patients in whom slight pain, stiffness, and tenderness persist in certain joints for weeks or months. These continuing symptoms might easily be due to a persistence of focal lesions of a subacute or chronic character. The intensity of the response about the joints is probably an important factor in the complete healing of arthritic lesions. The synovia and perisynovial tissues are rich in blood vessels and hence are in a condition to respond quickly and intensely to many small focal injuries.

In subcutaneous nodules, on the other hand, the tissue involved is less vascular; acute exudation is less marked than about joints; perivascular cellular proliferation is very marked, and the slower type of response is made evident by a slower disappearance of the evidence of injury. As already mentioned, the absence of nerves in the tissues implicated by subcutaneous nodules easily explains the lack of pain or tenderness about them.

With an understanding of what happens about joints and in subcutaneous nodules it is not difficult to construct a picture of the various cardiac lesions. The Aschoff body closely reproduces the changes seen about a single vessel in a subcutaneous nodule. There is a smaller amount of connective tissue than is present about subcutaneous nodules and, in addition, as the nodules usually occur about small arteries, their microscopic size is easily understood. Again a low degree of vascularity compared with the articular tissues explains the comparatively small amount of exudation; but exudation is suggested by the rapidity with which electrocardiographic signs of myocardial involvement appear and disappear during the acute stages of rheumatic fever. Partial or complete occlusion of the arteries would also result in a compromising of the nutrition of the portion of the heart supplied by them. There is also actual destruction of muscle fibers to explain certain symptoms of myocardial disease. It is, therefore, probably not overstressing the point to contend that in

rheumatic fever disturbance of cardiac function makes evident the presence of focal lesions in the myocardium, or cardiac blood vessels.

Focal lesions of the pericardium, if small, may result in a localized pericarditis and, on the other hand, if extensive, may be followed by extensive exudation. In fact, outpouring of a serofibrinous exudate is the usual mode of response to injury of large endothelial lined cavities like the pericardium and pleura, even though the character of lesions produced by the causative organisms in other tissues is usually focal in nature; for example, tuberculosis of the pleura or pericardium is ordinarily accompanied by a serofibrinous exudate. The organization of this exudate with the secondary changes incident to such organization is merely the logical outcome of a widespread pericarditis.

The peculiar character of rheumatic valvular endocarditis is more difficult to reconcile with the other focal lesions of this disease. As already mentioned, if we conceive of an edema of the valve occurring as an exudative response about focal rheumatic lesions in the valve substance or valve ring, it is not difficult to see how the endothelium at the line of closure would be injured and small thrombi deposited on the valves at this site of injury. The healing of these thrombi must be necessarily accompanied by formation of new blood vessels and fibrous tissue; and with this process there is not only the scarring of the valves leading to a disturbance of their function, but also the production of a *locus minoris resistentiæ* in or about which subsequent relapses of rheumatic fever are liable to set up new foci of inflammation. It is only fair to state that we do not understand the exact mechanism by which chronic inflammation of the valves leads to progressive narrowing or funnel-shaped deformities.

The manner in which multiple vascular and perivascular lesions in the brain set up the symptoms of chorea is not entirely clear. In chorea, however, there is usually evidence of a widespread encephalitis. Sometimes practically all of the voluntary movements of the body are rendered incoördinate; at other times the symptoms point to a less extensive distribution of the pathological process. Nevertheless, we practically never encounter evidence of large, single lesions in the central nervous system, such as we see in syphilis. The symp-

toms of implication of the central nervous system by the virus of rheumatic fever, therefore, point to the existence of many small foci, similar in nature to those found in other tissues of the body.

Doubtless comparable lesions in other organs or tissues are not infrequently present, but are not detected either because they fail to give rise to symptoms or because the usual well-marked manifestations of the disease outweigh them in prominence.

The perivascular proliferative type of lesion, resembling an infectious granuloma, explains the subacute and chronic character of the clinical symptoms in many cases of rheumatic fever. Marked exudation of serum into the periarticular tissues and of serum and cells into the joint cavities are concomitants of the acute arthritis occurring with high fever and general intoxication; these acute exudations disappear following the administration of certain drugs. But their disappearance does not prove that all of the proliferative types of lesions have resolved. In fact, we know that these last-mentioned types, when present in the subcutaneous tissues, often continue for months; and from analogy we may conclude that they have a similar persistent character in other tissues of the body invaded by the virus of rheumatic fever.

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THE SIGNIFICANCE OF THE GALL BLADDER.

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It is a singular fact that certain closely related species of animals have, some of them, a gall bladder, while others do not. What can be the essential significance of the organ and the reason for this difference?

Embryologically, the *vesica fellea* arises secondarily as a *cul-de-sac* from the same *anlage* that forms the liver and bile ducts, and it is considered by many as an almost purposeless diverticulum. Its irregular distribution in both high and low forms of life is noteworthy. Thus among the higher animals it is present in the cow and sheep, while it is absent in the horse, present in the goat, and absent in the closely related deer—to be found in the hog and wild boar, but not in the peccary of South America. Among birds, the hawk and owl possess it, while doves do not; and among the rodents the mouse is found with the organ, the rat without. One species of gopher,[1] the pocket gopher (*Geomys bursarius*) is without a gall bladder, while another (*Spermophilus tredecimlineatus*), the striped gopher, possesses it. Woods Hutchinson[2] is authority for the statement that in the giraffe it is at times present and again not.

Nevertheless, when present, it exercises a distinct influence over the character of the bile, as shown by the fact that the secretion contained in it is more concentrated than liver bile and of somewhat different constitution.

To test the concentrating ability of the organ a method was devised[3] by which bile of known constitution might be supplied through the normal channels to the intact gall bladder from the animal's own liver. The arrangement of ducts in the dog makes this possible. In this animal the liver consists of two large masses of tissue, the greater

[1] Mann, F. C., *Jour. Lab. and Clin. Med.*, 1919–1920, V., 107.

[2] Hutchinson, Woods, *Medical Record*, 1903, LXIII., 770.

[3] Rous, P., and McMaster, P. D., *Jour. Exper. Med.*, 1923, XXXVII., 11.

or main liver made up of three lobes comprising about 70 per cent. of the whole, and a smaller portion, the two posterior lobes, which have a separate duct and are quite distinct from the rest of the tissue. The common duct is formed by the union of three large branches, the gall bladder entering high up in the middle one, and below is joined by the duct from the posterior lobe. If canulas are inserted in the individual ducts, bile from the different lobes of the liver can be collected.[4] It is possible, with proper surgical precautions, to obtain sterile bile daily[3] over a period of months, draining it into rubber balloons suspended in wicker baskets outside the abdomen, the animals meanwhile remaining in excellent condition and uninfected. Such sterile bile can be had from the whole liver or its individual lobes and subjected to any desired analysis.

We first ascertained that bile coming from different portions of the same liver at one time, when the gall bladder is occluded by ligature, has approximately the same amount of pigment per cubic centimeter. With this determined observations were begun on the activity of the gall bladder. Through a slit in the common duct at a point above the entrance of the duct from the lateral liver mass, a catheter was run up into the gall bladder, its contents removed, and the organ washed clean with normal saline solution, after which the catheter was withdrawn and a ligature was placed on the duct above the slit. In this way bile from the major portion of the liver flowed into the gall bladder. That from the lateral mass was collected into a rubber balloon for comparison with that later found within the gall bladder. The period of experiment ranged from 22½ to 49 hours. Even at the end of this time the gall bladder was never unduly distended. The large amount of bile coming to it had been concentrated to a few cubic centimeters. Comparison with the control specimen showed that on the average there had been an eightfold concentration of the secretion. In another series of animals the gall bladder was filled with a sterile bile of known pigment content before the wash catheter was withdrawn. So rapidly was fluid removed through the bladder wall that even the increments of hepatic bile from the main liver were insufficient to distend the organ. The average concentration effected in this series was 6.4 fold.

[4] Rous, P., and McMaster, P. D., *Jour. Exper. Med.*, 1921, XXXIV., 47.

In a third set of experiments it was shown that merely in passage through the gall bladder to a balloon connected with its tip, bile was concentrated 2.3 to 4.8 times.

Opposed to the activity of the gall bladder upon the bile is the influence of the ducts.[5] These act to dilute it slightly with a thin secretion of their own, which can be collected into a rubber bag from an isolated duct segment. The secretion is pale, colorless, devoid of pigment and bile salts, and plays an important rôle in stasis. When the common duct is ligated and the gall bladder left in connection therewith, the stasis bile becomes in time much inspissated and far darker than normal in all the ducts, as would naturally follow from the concentrating activity of the bladder and the secondary changes in the bile. But if ducts are obstructed separately, the bile at first pent in them is little by little replaced by the colorless, thin duct secretion. If the common duct is ligated and the cystic duct as well, or if the obstructed ducts are left in communication with a gall bladder so changed pathologically that it ceases to concentrate bile, the ducts become filled with this colorless fluid. It is the white bile of surgeons.

The differing influences of the ducts and bladder upon the bile obviously have much to do with the site of origin of calculi. The concentrating activity of the gall bladder is a potent element in the formation of gall stones. Stasis gives opportunity for excessive inspissation; and in this way a normal gall bladder can become, merely through its functional activity, a menace to the organism.

In animals possessing no gall bladder, is the function of the organ lodged in the ducts? Advantage was taken of the circumstances that the rat has no gall bladder, whereas the mouse possesses one. It was found that in rats with common duct tied the bile is not concentrated, but replaced by duct secretion, whereas in the mouse it becomes greatly concentrated, obviously through gall bladder activity. One must conclude that not only the organ, but its function, is lacking in the rat. On the other hand, as bile collection showed, the secretion comes from the liver in far more concentrated form in the rat than in the mouse.

In animals permanently intubated for the daily collection of bile, calculi often develop in the collecting system, sometimes in as brief a

[5] Rous, P., and McMaster, P. D., *Jour. Exper. Med.*, 1921, XXXIV., 75.

period as 14 days. They form when the gall bladder activity is ruled out by ligation of the cystic duct and in the absence of infection and stasis.[6] The stones are made up chiefly of calcium carbonate and calcium bilirubinate. Pure calcium carbonate stones may develop in association with organic debris, but in other instances rounded pigmented particles appear in the bile, and on them the calculi later form. The presence of identical particles in centrifuged sediments of specimens of bile obtained after intubation makes possible the study of the early stages of stone formation. About the second day after operation the bile sediment is seen to contain great numbers of these light brown, refractile, translucent bodies. They are irregular in shape, doubly refractile, and are almost insoluble in water, alcohol, ether, and chloroform, but dissolve in chloroform to which acid has been added and in aqueous solutions of acid reaction. These bodies act as nuclei for calculus formation. By the third to fifth day after operation some of them are found encrusted with calcium carbonate crystals. After this the bodies are not found in the bile. Only crystals are to be seen unless some liver derangement occurs, when they may again appear in numbers and the crystals again be deposited upon them. This has been observed after poisoning by toluylendiamin, chloroform, and intravenous injections of calcium chloride.

Loss of all of the bile is not a factor in the formation of the stones, for when small glass tubes are interpolated in the ducts and the intestinal connection is left undisturbed, calculi still form upon the tubes. They are never found in the ducts or the gall bladder, despite the concentrating activity of the latter tissue, and masses of cellular debris which it frequently contains. Were such debris present in the glass-rubber collecting system, it would surely lead to calculus formation. The ducts, provided with musculature and a secretion of their own,[5] may, of course, easily free themselves of such debris. The cause for the absence of stones from the gall bladder contents is to be found in a change in the reaction of the bile, the fluid becoming acid as has been noted previously.[7] Hepatic duct bile shows a pH 7.5–8.5, that of the gall bladder has been found as low

[6] Rous, P., McMaster, P. D., and Drury, D. R., *Proc. Soc. Exper. Biol. and Med.*, 1923, XX., 315.

[7] Okada, S., *Jour. Physiol.*, 1915–1916, I., 114.

as 5.18, electrometrically determined. If liver bile containing the sediment of the sort from which stones develop is rendered acid by the addition of N/10 HCl or 3 per cent. acetic acid, the sediment goes into solution. The normally functioning gall bladder, then, effects the change necessary to keep the stone-forming substances in solution.

Summary.

The gall bladder acts not only as a distensible bag interpolated into a rigid system of tubes to minimize extremes of pressure, but as an important reservoir rendered capacious by its ability to reduce the bulk of the fluid stored within it. During periods when the duodenum is empty of food the gall bladder conserves the bile for future use, and through its concentrating activity is enabled to retain very nearly all the liver output. This concentrating faculty is of the greatest importance in the production of gall stones.

In many kinds of liver derangement the bile contains bodies which may act and on occasion—as when gall bladder activity is ruled out—do act as potential nuclei for calculus formation. But the normal organ, though concentrating the bile, effects a change in its reaction which renders stone formation impossible. If it fail to function normally, stones may readily form.

The facts here set forth for the dog remain to be proved for man.

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THE STRATIGRAPHY OF THE WHITE RIVER BEDS OF SOUTH DAKOTA.[1]

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(Read April 20, 1923.)

[1] Investigation aided by a grant from the Marsh Fund of the National Academy of Sciences.

I. Introduction.

In an earlier paper the writer published the results of a microscopic study of the sediments of the White River series in the Big Badlands of Pennington and Washington Counties in southwestern South Dakota, and discussed the various types of sediments represented in this area. The clastic sediments of the White River beds were there shown to be, in large part, derived from the Black Hills uplift, which lies about 50 miles to the west of the Big Badlands. The abundance of wind-blown volcanic ash in the upper part of the White River beds was also pointed out.

The present paper aims (1) to present a stratigraphic study of the various formations of White River age in the same area, with a description of several well-distributed sections, showing the vertical succession of the various types of sediments discussed in the earlier paper; (2) to make certain changes in the sections published in the previous paper as the result of the subsequent discovery of a few definite horizon markers of wide geographic distribution; (3) to show the remarkable continuity and uniformity over immense areas of certain members of the White River series; (4) to present in outline the successive interpretations given to the climate and physiography of White River time by geologists of the past 70 years, with a critical discussion of their views; (5) to interpret the climatic and physiographic significance of the various types of sediments observed in the badlands, based upon their lithologic character, the presence of concretions and other structures, and the conditions under which fossils of White River time are found preserved; (6) to present an outline of the physiographic and climatic changes to which the area of the Big Badlands has been subject between the withdrawal of the Cordilleran sea of Cretaceous time and the close of White River deposition, as these changes are represented by sediments or erosional unconformities; (7) to deduce from the distribution of volcanic ash of White River and Lower Miocene date the source of the volcanic material and some measure of the magnitude of the eruptions which supplied this ash; (8) to attempt an explanation of the relations between sandstone dikes and chalcedony veins, the silicification of limestones and gypsum beds, and the development of caliche layers, accept-

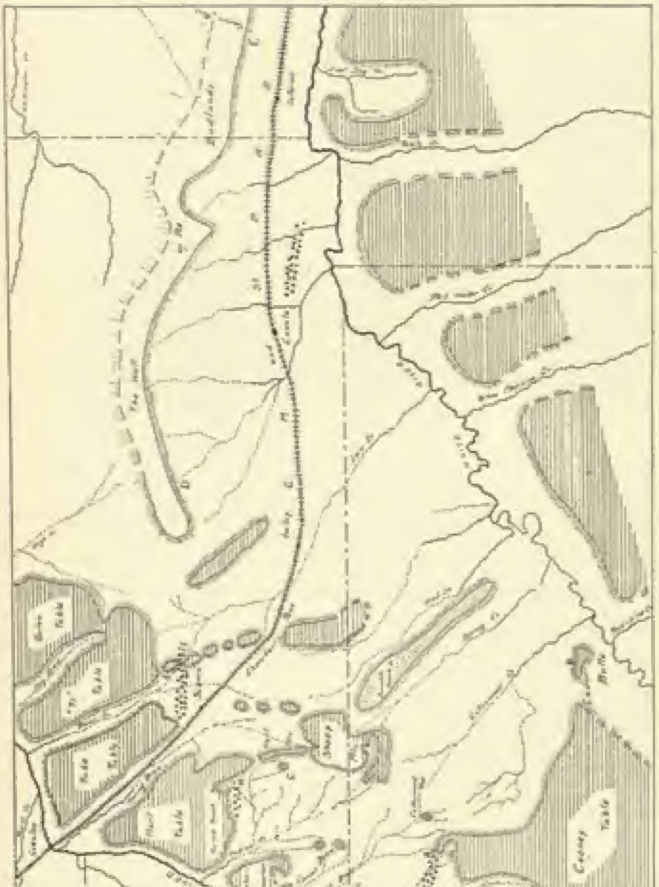


FIG. 1. Sketch map of a portion of the Big Badlands of South Dakota, showing the distribution of the table lands and other remnants of the high plain (horizontal shading), dune sand deposits (light dots), and pre-Cheyenne River gravel channels (lines of heavy dots), and the positions of the columnar sections (*A–H*). Adapted from Map of Interior District (White & Campbell), Map of the Pine Ridge Indian Reservation (Dept. of the Interior, Office of Indian Affairs, 1914), and Map of the White River Badland Formations of the Black Hills Region (O'Hara, 1920). Scale 1/570240. (9 miles = 1".)

ing the theory that the fissures which are occupied by these dikes and veins were formed by desiccation; and finally (9) to present briefly some evidence on the stages of post-Oligocene erosion and deposition and climatic change in the area, and to suggest explanations for some of them.

It is the hope of the writer that this paper may establish a standard section of the White River formations in their type locality, which will be of value in correlating the elements of the White River in other districts.

The field and laboratory work upon which this paper is based has been done under the direction of Dr. W. J. Sinclair, of Princeton University, who has given the writer the benefit of his broad experience with western Tertiaries in passing on various theories developed to explain relations or structures observed in the field. The field work was done during the summers of 1920, 1921, and 1922, under the auspices of the Department of Geology of Princeton University, assisted by a grant from the Marsh Fund of the National Academy of Sciences. Dr. A. H. Phillips kindly analyzed a sample of the clays of the "Interior" beds and has given valuable assistance in interpreting some of the chemical problems involved. Dr. A. H. Pillsbry, of the Philadelphia Academy of Sciences, has identified some of the fresh-water and land invertebrates found in the White River, and Dr. R. W. Chaney, of the Carnegie Institution, has studied some petrified wood collected in the Titanotherium beds and supplied the writer with data on the climatic range of *Celtis*. The writer is also indebted to Professor W. B. Scott and to the late Mr. T. B. Lawler, of Princeton University, for frequent helpful suggestions, and to Mr. J. B. Mawdsley for assistance in the preparation of some of the illustrations.

II. Stratigraphy.

Pierre Shale.—The Pierre shale underlies the White River formations throughout the area of the Big Badlands. It is everywhere a gray shale which weathers very easily to a dark gray or black mud. Even fresh samples are so soft as to be easily broken or crumbled between the fingers. Bedding is not visible in the Pierre except where it is emphasized by levels of concretions. The Pierre contains

a rich marine Cretaceous fauna, and at almost any outcrop fragments or shells of *Inoceramus, Baculites, Scaphites, Placenticeras,* and other forms may be discovered with a little search, the original thin pearly iridescent outer layer being frequently preserved. Crystals of gypsum occur abundantly in this shale and springs emerging from it are strongly impregnated with sodium sulphate. At various levels there occur large round or flattened oval siliceous concretions, which contain marine fossils more abundantly than does the rest of the shale.

The Interior Formation of Ward.[1]—The surface of the Pierre shale upon which the White River deposits rest is very irregular. In the area of the Big Badlands the maximum relief of this surface may be from 50 to 100 feet, though no exact figures are available. It is possible that later formations may have been deposited in this area and subsequently removed by erosion. At many points in the Big Badlands there is a gradational change from the dark gray alkaline shales of the Pierre to the greenish clays and silts of the Titanotherium beds. This zone of gradation has a thickness of 38 to 45 feet and consists of lavender and blue clays, weathering to a rusty brown color diversified by calcareous nodules with cone-in-cone structure and concentrically banded nodules of pink or red color strongly impregnated with oxides of iron, each type of nodules being developed along definite horizons. In other sections the contact between the Pierre shale and the Titanotherium beds is abrupt, a thin bed of pebbles of quartz, feldspar, and igneous and metamorphic rocks derived from the pre-Cambrian of the Black Hills, resting immediately on the shale. Where the blue and lavender clays are absent the sands and silts which occur at the very base of the White River formation are stained an ochre yellow by saturation with hydrated oxide of iron. This is a local hardpan formed by the ground water where the impervious shale limits further downward circulation.

These lavender and blue concretionary clays have been named the "Interior formation" by Professor Ward in a recent paper,[2] because of their development in the vicinity of Interior, Jackson Co., South Dakota. He believes that the color is primary, and that these clays represent the Fox Hills, following without break after the Pierre.

[1] South Dakota Geol. and Nat. Hist. Survey, Bull. 11, pp. 18–20.

[2] Ibid.

Professor Toepelman[3] suggests that "they may be a slightly sandy phase of the Pierre, such as are now being made known from many localities with the typical blue-black color of the shale, and have subsequently been changed in color through the process of weathering and the circulation of waters from the overlying Tertiary." Three vertebræ in articulation, probably mosasaurian, were found in the clays of the "Interior" beds by the Princeton 1922 expedition in the valley of Bear Creek 2 miles north of Scenic. Loomis[4] discovered a large Pierre fauna in these clays in Spring Creek, west of Scenic, and at lower levels some *Titanotherium* bones in place, indicating that a part of the material had been reworked and that some of the Cretaceous fossils might be remanie.

In the "Interior" formation at several points flattened, convex, lens-shaped concretions with an average diameter of 2 to 3 feet and an average thickness of a foot to 18 inches are developed. These are colored a light chocolate brown and show cone-in-cone structure along the top and bottom in bands about 4 to 6 inches thick. These concretions often contain in their centers weathered casts of the shells of *Baculites* and *Inoceramus*. Loomis[5] has published a list of fossils found in the Interior beds in Spring Creek, many of which are from these cone-in-cone concretions. An analysis of some of the cone-in-cone material showed 73 per cent. of soluble carbonates, presumably $CaCO_3$. Tarr[6] has discussed the origin of cone-in-cone and assigns it tentatively to pressure phenomena developed by the recrystallization of aragonite to calcite. Similar concretions occur along regular horizons, and at various levels through the Pierre shale,[7] and their origin is probably not a part of the White River problem.

In the upper part of the Interior formation are one or two levels characterized by rounded or flattened oval concretions which in section are seen to be formed about a clay center, and show concentric bands of varying shades of brown, colored by hydrated oxides of iron. A test showed a very small percentage (less than 3 per cent.) of cal-

[3] Ibid., p. 64.

[4] *Science*, N. S., Vol. 19, p. 254, 1904.

[5] Ibid.

[6] *Am. Jour. Sci.*, 5th Series, Vol. IV., pp. 199–214.

[7] "W. A. Tarr, "Syngenetic Origin of Concretions in Shale," *Bull. Geol. Soc. Amer.*, Vol. 32, 1921, pp. 373–384.

careous cement in these concretions. Their origin is not clear, but they seem to represent a product of concentration formed on an old land surface with the help of cementation by iron compounds in the ground water. Pilgrim,[8] in speaking of concretionary layers in the Siwaliks, describes them as pseudo-lateritic in origin, and it is believed that these also may have been formed in a laterite. No fossils have been discovered in this type of concretion.

An analysis of a sample of the lavender clay of the "Interior" beds from the valley of Bear Creek, 2 miles north of Scenic, by Professor A. H. Phillips follows (1), contrasted with an analysis of the typical Pierre shale (2) from Pueblo, Colorado:[9]

	(1) Lavendar Clay of "Interior" beds, Bear Cr., 2 miles north of Scenic, S. D., Phillips, analyst.	(2) Tepee Zone of Pierre Formation, Pueblo, Colo., Steiger, analyst.
SiO_2	61.20	60.80
TiO_2	.58	.47
Al_2O_3	18.75	15.63
Fe_2O_3	4.39	4.52
FeO	.73	....
MnO	.06	....
CaO	.37	1.63
MgO	1.06	2.73
K_2O	3.83	2.55
Na_2O	1.59	1.45
P_2O_5	.09	.10
$H_2O < 110°$ C.	2.73	3.19
Loss on Ignition	4.72	4.16 $H_2O > 100°$ C. 2.87 Organic.
	100.10	100.20

The noteworthy features of the chemical composition of the "Interior" clays are: (1) that the total percentage of iron oxides is somewhat higher than in the underlying Pierre; (2) the percentages of lime and magnesia are notably lower; and (3) the percentage of potash is considerably higher than that of the Pierre. The proportion of iron oxides given is lower than the average for the "Interior"

[8] Records of Geol. Survey of India, Vol. XLII., Pt. 4, 1913.

[9] U. S. G. S., Geol. Atlas of the U. S. Pueblo Folio No. 36, p. 7.

FIG. 1. Divisions 4 (foreground) and 5 of the Oreodon beds, with overlying Leptauchenia beds, along the edge of Cooney Table in Battle Creek Draw. Marginal numbering corresponds to divisions in Text Fig. 5, A2, and Text Fig. 9A.

FIG. 2. Contact of Pierre shale (dark beds in lower half of picture) and Titanotherium beds, at main forks of Indian Creek.

beds as a whole because of the levels of concretions rich in hydrated ferric oxides in the upper part of the series. Concentration of iron and potash and diminution of the lime and magnesia content are characteristic results of weathering and leaching, suggesting that the "Interior" formation represents the less soluble materials of overlying beds, which were eroded before White River time.

The relation of the "Interior" beds to the Pierre shale is an interesting problem. The wide distribution and uniform thickness of the "Interior" beds lead Ward[10] to believe that their peculiar characteristics are primary, and that they were deposited at a stage of the withdrawal of the great Cretaceous Cordilleran sea. He writes: "The most rational view seems to consider the material to have originally been just as different from the typical Pierre as it is seen to be today. Then follows the interpretation of a shallowing sea, a nearer shore line, a changing geography, an accompanying diastrophism."

The writer is inclined to agree with Toepelman in his opinion, cited above, that the color is secondary and due to the concentration of iron from the erosion of the Pierre and overlying beds during Eocene, or at least pre-White River time. The peculiar characters of this bed and its wide distribution below the Titanotherium beds lead the writer to believe that it was formed rather by weathering and leaching on the surface during a long period of pre-White River erosion than that its characters are primary as Ward suggests. It is unlikely that a bed as thin as this would happen to be the surface on which deposition began over a wide area, after a period of erosion as long as that from the later Cretaceous to the Oligocene. The thickness of this bed, 38 to 45 feet, suggests that weathering and iron impregnation took place to that depth. Such deep weathering is characteristic of warm and humid climates, hence the period of formation of the Interior type of clays may have been warm and subhumid. The surface of the "Interior" formation seems to have been essentially a peneplain, for it shows only minor irregularity. In the upper part of the Interior formation, besides the concentrically banded iron concretions described above, there are found numerous narrow veins (½ to 2 inches in width) filled with limonite. As

[10] Op. cit., p. 19.

ferric iron is a comparatively rare constituent of the Pierre shale (about 2 per cent.), this abundant occurrence of it near the old surface may represent the erosion of a considerable thickness of later beds with concentration of their iron content. Some of this iron may have been leached out of the overlying White River clays and precipitated where the downward circulation of water is stopped by the impervious Pierre shales.

As pointed out above, in some sections of the Big Badlands the " Interior " beds are absent, and the White River (Titanotherium) sands and silts rest directly upon the Pierre shale. The north branch of Indian Creek, about 4 miles southwest of Scenic in Pennington Co., shows sections where the Interior clays are present and others where they are absent. Two sections in Indian Creek (*G*) and (*H*) and one in Bear Creek valley 3 miles northeast of Scenic (*F*), (near the locality where Thaddeus Culbertson made the first collection of badland fossils in 1850), whose geographic positions are given on the map, Fig. 1, are presented in Fig. 2. It will be observed that the thicknesses of Titanotherium clay overlying the Interior beds in (*F*) and (*G*) are, respectively, 72½ and 71 feet. In (*H*), where the Interior beds are absent, the normal gray clays of the Titanotherium beds are 73 feet thick, and below them are 10 feet of channel sandstone, 49 feet of irregularly banded pink clays and green silts, and a thin basal conglomerate. The great uniformity in thickness of the Titanotherium beds above the level of the " Interior " beds (71, 72½, and 73 ft.) indicates that deposition of the later Titanotherium beds began on a plain in which the streams flowed in shallow channels, thus continuing the peneplain of erosion of which the " Interior " beds are the surface. For convenience this may be termed the Interior peneplain. The 60 feet of silts, sands, and gravels of Titanotherium age deposited below the level of the top of the " Interior " beds (Fig. 2, Section *H*) were evidently laid down in valleys which had been cut below this peneplain shortly before the beginning of White River time. In the north branch of Indian Creek, about ½ mile south of E. H. Taylor's ranch on Hart Table, one passes abruptly within 100 yards on the same contour from a section of 40 feet of Interior clays to 50 or 60 feet of Titanotherium silts, sands, and

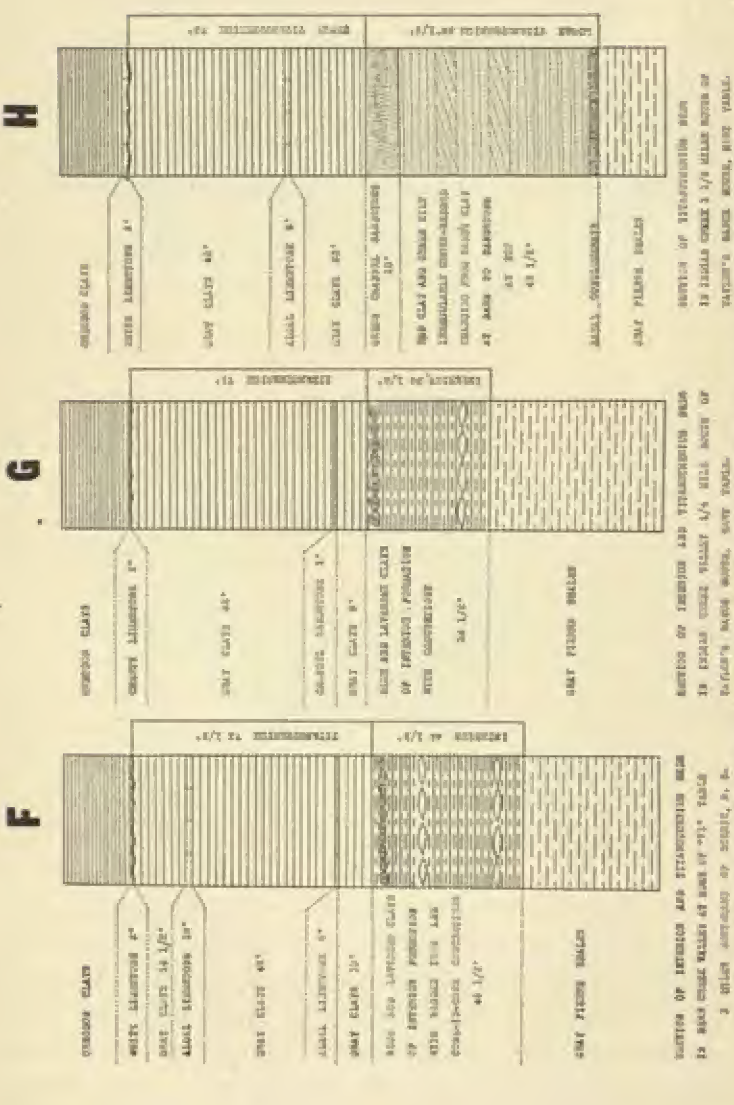


FIG. 2. Parallel columnar sections of the Titanotherium and "Interior" formations in the vicinity of Scenic, S. D. (*F–H* on the map, Fig. 1.) Vertical scale 60' = 1".

gravels. This indicates that the walls of the valley were quite abrupt. Pre-White River erosion in the north branch of Indian Creek had evidently removed the "Interior" beds and cut 15 or 20 feet into the underlying Pierre shale. Farther south (toward the center of the valley), where a massive sandstone 20 feet thick with a thin gravel bed at its base rests directly on the Pierre shale (see Plate 1, Fig. 2), the depth of erosion may have been still greater, but as the full section of the Titanotherium beds is not preserved there, it was impossible to measure the degree of erosion. The width of this valley was probably from 3 to 5 miles or more, for the "Interior" beds do not outcrop again until 8 or 10 miles to the south, in the lower parts of Corral, Quinn, and Battle Creek Draws. Figure 3 is a diagrammatic sketch of this valley cut in the "Interior" peneplain. The shape of this valley is hypothetical, but the left side of the diagram is based upon the sections measured in Indian Creek.

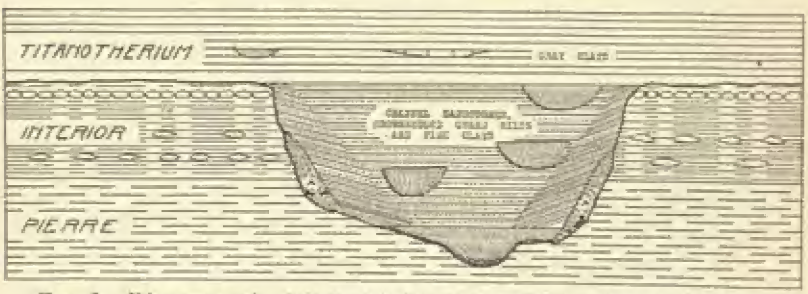


FIG. 3. Diagrammatic sketch showing the probable relations between the Pierre, "Interior," and Titanotherium beds, as observed on the North Branch of Indian Creek, 5 miles southwest of Scenic, based on Sections *G* and *H*. Vertical scale 60′ = 1″.

The preservation of Titanotherium bones at lower positions than Cretaceous marine fossils, as reported by Loomis,[11] might be possible along the sides of the valley where talus slopes or slumping of the "Interior" (Cretaceous) clays might bury occasional bones of Titanotheres or other White River animals (*A*, Fig. 3).

At the base of the Titanotherium beds deposited in the valleys eroded in the "Interior" peneplain is a gravel bed from three inches to a foot thick containing pebbles derived from the pre-Cambrian

[11] Op. cit.

section of the Black Hills. The pebbles of these gravels are larger in average size than those usually found in the channel deposits of the White River beds, but smaller in average size than the Pleistocene gravels described in a later section, usually being from one to three inches in diameter.

It was observed that the Titanotherium beds filling the valleys in the "Interior" peneplain are strongly colored in irregular bands, often resembling cross-bedding. The clays and finer silts are usually pink or red, while the coarser silts and sands are green. These pink clays and green silts are often steeply cross-bedded with observed slopes of 40° or more. These may represent the foreset beds of lateral delta terraces along the sides of the valley formed during its aggradation. Sometimes thin seams of fine gravel are observed between the bands of pink clay and green silt. The disappearance of the color banding as soon as the horizontal level of the old surface of the "Interior" beds is reached by channel filling and the extension of the Titanotherium clays as a cover over the "Interior" beds, protecting them from erosion, suggest that the coloring matter in the early Titanotherium beds was derived from the iron-stained "Interior" formation.

The initiation of erosion giving rise to the channels in which the lower Titanotherium sands were deposited must have been due either to uplift, a change of climate, or a combination of these factors. The Black Hills are believed by many geologists [12] to have been either completely submerged or nearly so during the time of the great Cordilleran sea of Cretaceous age. Cretaceous sediments are found with steep dips on the flanks of the Hills. If this was the case, the doming uplift with accompanying dissection must have taken place following the Cretaceous, for with the very beginning of Oligocene sedimentation (basal gravels of the Titanotherium beds) the granites, pegmatites, and schists of the pre-Cambrian core of the Hills were exposed to active erosion. It is probable that during the period of weathering resulting in the formation of the "Interior" beds the Black Hills were well mantled with vegetation and therefore not strongly eroded. Their altitude above the plain may have been less than at present, for

[12] Darton, "Geology of Southern Black Hills Region," U. S. G. S., 21st Ann. Rept., Vol. 4, 1900, pp. 556–558.

there has undoubtedly been marked uplift of the Hills since White River time.

After the formation of the "Interior" peneplain a climatic change involving greater aridity may have stripped the surface of most of its vegetation and allowed the surface soil to be removed more rapidly. With less soil and vegetation to hold the water, the rain, falling in cloudbursts and violent storms characteristic of an arid climate, may have run off rapidly and cut channels for itself in the soft shales of the "Interior" beds, thus rejuvenating the streams which had previously flowed across the surface of the plain in shallow channels. This dissection probably continued until the desiccation had also begun to affect the Black Hills. During this time a valley, or rather valleys, from one to several miles wide were formed, in which the rejuvenated streams flowed, but the period of erosion was evidently not long enough to smooth out the topography, as shown by the abruptness of the valley edge in Indian Creek, referred to above.

As the rock surface of the Black Hills became more exposed to erosion through the removal of soil and organic debris, the streams leading from this uplift out upon the plains carried a larger amount of clastic material, and soon this began to be deposited as sand and gravel in the stream beds. Thus the sandstones and conglomerate at the base of the White River had their origin. After the channel cutting, aggradation assumed a predominance over degradation in the area of the present Big Badlands which it retained throughout White River time. When the narrow central channel was filled, the streams spread sheets of silt over the valley floor, and occasionally shifted their channels. Lateral delta terraces, now represented by steep cross-bedding in the pink and green silts, formed along the sides of the valleys. This deposition of sandstones and pink and green silts continued until the valley had been completely filled and the old peneplained surface reformed as a plain of aggradation. Then the Titanotherium beds channels were free to wander over the plain at will and the uneroded portions of the "Interior" beds were preserved under a cover of gray Titanotherium clay.

The Titanotherium Beds.—The Titanotherium beds are distributed widely through western South Dakota and Nebraska, as well as

in northeastern Colorado and eastern and central Wyoming, but they have been studied by the writer only in the region of the Big Badlands of South Dakota. They have been described by Hatcher,[13] and their character in regions other than South Dakota, discussed by Matthew[14] for northeastern Colorado, Darton[15] for western Nebraska and eastern Wyoming, and Sinclair and Granger[16] for the Wind River and Big Horn basins. In the South Dakota Big Badlands the Titanotherium beds consist of spongy clay or silt, sandstones, conglomerates, and fresh-water limestones. All of these are subject to sharp lateral variation. The earlier writers held that the Titanotherium beds, as well as the other elements of the White River, were deposited on the bottoms of large lakes in quiet water. This view was supported by Hatcher in his paper on the Titanotherium beds, but was later abandoned[17] and a fluviatile hypothesis substituted. Fraas[18] believed that the Titanotherium beds were "deposited in a slow-moving river which emptied into a broad delta on level stretches of the Fort Pierre." He refers to conglomerate at the base of the Titanotherium beds.

It is more difficult to interpret the history of the Titanotherium beds than that of the later members of the White River because of their variability in thickness and lithologic character from point to point. Over large areas the whole of the Titanotherium beds is represented by spongy gray clays with occasional thin bands of limestone. In other areas sandstones and conglomerates from old stream deposits form a very prominent part of the section. It is in the latter that the remains of Titanotherium and other contemporary mammals are most commonly preserved. It is not usually possible to follow the courses of single channels clearly in the Titanotherium beds, although it appears that the general direction of flow was to the southeast or east. There were probably streams with shifting channels which frequently overflowed their banks and formed the widespread

[13] *Am. Nat.*, Vol. 27, 1893, pp. 204–221.

[14] *Mem. Am. Mus. Nat. Hist.*, Vol. 1, Pt. 7, 1901, p. 356.

[15] U. S. G. S., Prof. Paper 17, p. 40; Prof. Paper 32, pp. 169–175. Geol. Atlas, Folios 85, 88, 91, 173; 21st Ann. Rept., Vol. 4, 1900, pp. 542–545.

[16] *Am. Mus. Nat. Hist. Bull.*, Vol. XXX., pp. 83–117, 1911.

[17] *Am. Phil. Soc., Proc.*, Vol. 4, 1902, pp. 113–131.

[18] *Science*, N. S., Vol. 14, 1901, pp. 210–212.

clay deposits away from the channels. Channels were more numerous and a larger amount of coarse material was transported than in those cutting the Oreodon or Leptauchenia beds. The clastic material of the Titanotherium channel sandstones is mostly derived from the pre-Cambrian schists and pegmatites of the Black Hills, as noted by the writer in an earlier paper.

Another pronounced character of the Titanotherium beds is the abundance of fragments of fresh feldspar. This, in all samples studied, is predominantly microcline, and microcline is also the most abundant feldspar in the channel sands and gravels of all stages of the White River. Albite and oligoclase were rarely found, and orthoclase, when found, was more weathered than the other varieties. The gridiron structure of the microcline is usually very fresh. An interesting parallel to the White River channel sandstones is found in the Millstone grits of Yorkshire, described by Gilligan,[10] who states: "As with the larger pebbles, the dominant feldspar is microcline, next in order comes microcline-microperthite, then oligoclase, and orthoclase. Very basic feldspars appear to be altogether absent in the fresh state, and were never, I believe, present in any notable quantity. These feldspars are often exceedingly fresh. As in the larger pebbles, the cross-hatching of the microcline is wonderfully well shown, while the oligoclase is frequently quite unaltered. Microcline is, as is well known, the most resistant of all feldspars to alteration, and is found quite fresh in deposits of all ages."

Lenses of algal limestone, sometimes in the form of sheets and sometimes as levels of algal balls, all of which are local and generally very thin, from one to eight inches in thickness, are a common feature in the Titanotherium beds. At one locality in the basin of the north branch of Indian Creek algal balls were found which had grown around Unio shells. These were very abundant, forming a continuous sheet over an acre or so. At many places the limestones are irregularly replaced by silica in the form of opal or chalcedony. They were probably formed in shallow ponds on the surface of the flood plain in slight depressions where flood waters were undrained, the thinness of the limestone sheets indicating the temporary nature of these basins.

[10] *Quart. Jour. of Geol. Soc. of London*, Vol. LXXV., 1919, p. 262.

It is not evident whether the drainage of this region was carried through to an ocean basin at this time or not. The fact that the White River beds around Scenic have a larger number of channels than those near Interior, 30 miles farther from the Black Hills, suggests that the streams of White River time may have been distributaries spreading their deposits on a subaërial delta. Johnson[20] in describing the modern high plains points out that though the climate is not that of a desert and the region is not a structural basin, still "they have practically no drainage, the local precipitation being disposed of by absorption." The present is a period of erosion through the plains area as a whole, and the preservation of the high plains is partly due to a covering of sod, but during White River time the conditions favored aggradation rather than degradation, and it is quite reasonable to believe that the streams may have been distributaries from the points where they left the mountains until their disappearance by absorption and evaporation on the plain.

A fossil tree was found by the 1922 party almost at the base of the Titanotherium beds in the west branch of Corral Draw, with roots in the normal position of growth and sections of the trunk lying around near the stump. It has been submitted for study to Dr. R. W. Chaney, who reports that, from all the evidence at hand, it appears to be a *Celtis*.

As pointed out in the earlier paper, the Titanotherium clays are clearly differentiated from those of Oreodon age by a difference in their weathering characteristics. The slopes of the Titanotherium clay outcrops are rounded and deeply weathered. The writer, in endeavoring to obtain a fresh sample of this clay, dug into a bank to a depth of two or three feet, finding the clay below the surface quite damp, nearly saturated with water, and pale green in color. It is impossible to obtain a specimen of the clay which will not crumble to pieces on slight pressure of the hand. The amount of calcareous cementing material in the Titanotherium clays is distinctly less than that in the clays of the Oreodon beds, averaging only 1 to 5 per cent., while the Oreodon clays contain 10 to 30 per cent. The sharp change in the amount of cementing material at the contact seems to indicate that the cementation is not due to the activity of ground water after

[20] U. S. G. S., 21st Ann. Rept., Vol. 4, p. 610, 1900.

the deposition of the sediments. Therefore the change in the cement from Titanotherium to Oreodon clays indicates a change in the conditions of rainfall and surface water, and therefore a change in climate. The very discontinuous character of the clays and sandstone beds of Titanotherium age is also evidence of relatively humid climatic conditions.

According to Johnson,[21] "all streams carry rock material in solution, as well as a visible load in suspension, and commonly they are more or less 'hard' with dissolved calcium carbonate. But only desert streams deposit this chalky material upon their waste plains in appreciable quantity." The inference is that in a series of flood-plain clays those with a higher percentage of calcareous cement were deposited under more arid conditions than those with less calcareous cement, other factors such as the supply of calcium carbonate at the source remaining constant. Sheet flood action, when a flood from a river or a number of parallel rivers spreads over many miles of intervening flats, is also characteristic of semi-arid rather than of humid regions.

The conclusion to be drawn from the above facts with respect to the climate of Titanotherium time is that it was for the most part humid or semi-humid, and that the sediments were deposited in river channels and flood plains and as thin sheets spreading across the plain at times of torrential rainfall. The climate was seasonal, as the fossil tree found shows well-developed annual rings. Ponds were formed here and there on the surface of the plain in shallow depressions where the excess flood waters gathered and remained until evaporation or absorption had dried them up. In these ponds fresh-water algæ and some fresh-water mollusks flourished, at least while the water remained fresh. Probably the ponds were frozen over during the winter, at least occasionally, as the writer has several times found pebbles two or three inches in diameter embedded in the fine-grained calcareous deposits of the ponds. Ice seems to be the only agent capable of transporting such pebbles to the middle of a pond. There was probably a fairly rich cover of vegetation, though trees may have grown chiefly along the courses of streams. The *Titanotherium*, one of the largest land mammals of the earth's history, lived during this

[21] Ibid., p. 639 on.

period, and also, as Hatcher [22] pointed out, was undergoing rapid change toward its climax. The great size development of the Titanotheres may confirm other evidence presented above that the northern plains province during the period of deposition of the Titanotherium clays enjoyed a mild humid or sub-humid climate. It is a reasonable possibility that the extinction of the Titanotheres may have been brought about by a change to a period of less rainfall during Oreodon time.

On the other hand, the presence of gypsum in part of the Titanotherium beds shows that the favorable climate must have been interrupted by periods of marked aridity. It has not been observed by the writer, but is described as follows by Ward [23] for the Interior district: "One of the common variations is the presence of gypsum, which occurs only in the basal purple-red portion of the Titanotherium, but is found in many localities. There are no beds of this mineral. It occurs rather as irregular lumpy small masses usually only a few inches in diameter and with no alignment or evident plan or grouping. Occasionally several are connected. In some instances chalcedonic silica occurs with the gypsum, and, since on weathering, the gypsum is readily removed, the silica is at times found alone. A small amount of the gypsum is fibrous, occurring in narrow veins running in several directions with no well-established system." [23] Professor Fraas [24] mentions that "certain layers are very rich in gypsum and barite. Both minerals are now represented only in pseudomorphs of chalcedony, formed out of gypsum and barite." There are in several places large bell-shaped masses of chalcedony with hollow centers and botryoidal structure. These have been found up to a size of about one foot diameter. They are abundant in the lower Oreodon beds in Bear Creek basin about 5 miles south of Scenic. There are also frequent smaller concretions of chalcedony many of which Honess [25] has shown to be pseudomorphs after gypsum. He has also detected a little unreplaced gypsum. The writer has found a small nodule of tabular barite crystals in the badland

[22] *Am. Nat.*, Vol. 27, 1893, pp. 204–221.

[23] S. D. Geol. and Nat. Hist. Survey, Bull. 11, p. 22.

[24] Op. cit.

[25] *Amer. Jour. Sci.*, 4th Series, Vol. V., p. 173, February, 1923.

clays, and Honess detected barite crystals with calcite along the central unfilled portions of chalcedony veins, which are discussed below. Apparently the deposition of barite and gypsum took place throughout much of Titanotherium and Oreodon time, as the chalcedony pseudomorphs have quite a wide vertical distribution. They were probably desiccation products and it is observed that they are quite abundant in the lower red layer. Along the edge of Hart Table, 3 miles southwest of Scenic, a disconnected layer of chalcedony pseudomorphs was discovered, but they are usually found lying exposed on the surface, as they persist long after the removal of the clay by erosion. The gypsum may have been deposited in shallow playas during periods of unusual aridity in Titanotherium and Oreodon time.

The character and origin of the lower Titanotherium beds which were deposited in valleys cut into the peneplained surface of the Interior beds was fully discussed under the latter.

There are sandstone channels developed at various horizons within the Titanotherium beds, but it is rarely possible to follow a single channel for more than a quarter of a mile. The positions of two of these channels are shown in the sections in Fig. 2. In the valley of Indian Creek over quite a wide area a bed of channel sandstone from 15 to 25 feet in thickness rests directly on the Pierre shale surface. This is shown in Plate 1, Fig. 2. In Battle Creek draw over an area of several square miles are exposed uniform gray clays of the Titanotherium beds, with no channels and only occasional thin limestone lenses. In Corral Draw channels are numerous and at various levels, while at Interior no channels were observed, though Ward [26] in a detailed examination of the area found two small channel deposits in the Titanotherium beds.

Sandstone dikes and chalcedony veins occur throughout the Titanotherium beds, and will be treated separately in a later chapter.

Titanotherium-Oreodon Unconformity and Limestone Sheet.—Throughout the area of the Big Badlands and along the northern base of Pine Ridge, as described by Darton, there is a marked change in the character of the sediments at the contact between the Titano-

[26] Op. cit., pp. 21–22.

FIG. 1. Edge of Cooney Table, Battle Creek Draw, showing two algal limestone sheets (a', a'') in the Oreodon beds. Marginal numbering corresponds with Text Fig. 5, section A1, and with Text Figs. 4 and 9A.

FIG. 2. Looking across Indian Creek, above its main forks from the level of the peneplain at the top of the Titanotherium beds. Contact of the latter with the Pierre shale is indicated by the pointers.

therium and Oreodon beds. In the Big Badlands the contact is slightly irregular. It is marked at many points by the presence of a thin discontinuous sheet of algal limestone from one to six inches thick. This thin limestone sheet was observed all the way from the Wall of the Badlands, north of Interior, to the head of Cedar Creek, about 65 miles to the southwest. Darton mentions the presence of a sheet of limestone at the top of the Chadron at Goshen Hole, Wyoming, on the North Platte River, about 150 miles from the Big Badlands, and in western Nebraska.[27] At some places it is absent and often it is almost completely replaced by silica either as chalcedony (brown or black) or as opal (white). This represents deposition in a shallow body of water, or rather many distinct shallow ponds. It contains fresh-water mollusks which are characteristic of small glacial ponds at present. Dr. Pillsbry[28] recognizes *Lymnæa,* two small species of *Planorbis,* an Ostracod of the nature of *Cypris,* and a well-preserved fish-scale, probably a small member of the *Cyprinidæ,* in material from this limestone at the base of the Wall of the Badlands five miles northeast of Imlay. He writes: "This appears to be a pond or shallow lake fauna. The snails are such as occur at the present time in the zone of abundant plants mainly less than 20 feet in depth. Very similar deposits are forming now in some ponds of the glaciated region of northern New Jersey, New York, and all the northern states. The great extension of the deposit . . . suggests widespread marsh and pond conditions. The lack of any land snails as well as the almost purely calcareous nature of the sediment excludes the idea of anything of the order of loess."

There is evidence of moderate erosion between the close of Titanotherium deposition and the algal limestone and Oreodon beds. This is indicated by the degree of irregularity in the contact surface. In Battle Creek Draw the contact drops 15 or 20 feet in level in a quarter of a mile and a thin sheet of algal limestone rests on the clay over the entire slope, showing that the period of limestone formation succeeded the erosion interval. The length of the time interval between Oreodon and Titanotherium beds deposition may only

[27] Geological Atlas of the U. S., Hartville Folio (No. 91), p. 3.

[28] Personal communication.

be conjectured, but the average thickness of Titanotherium clays removed during this interval apparently did not exceed 20 feet. A photograph reproduced in Sinclair's paper on the "Turtle-Oreodon Layer"[29] shows the Titanotherium-Oreodon unconformity very clearly along the edge of Hart Table, but the asterisk in the margin indicating the contact was unfortunately placed by the printer ¼ inch too high. The "rather persistent bed of reddish clay above which an Oreodon beds fauna occurs" at Interior,[30] at which the base of the Oreodon beds was temporarily placed when the Interior section was first studied by us in 1920, has not been recognized elsewhere in the badlands, and is now regarded as of no significance as a horizon marker.

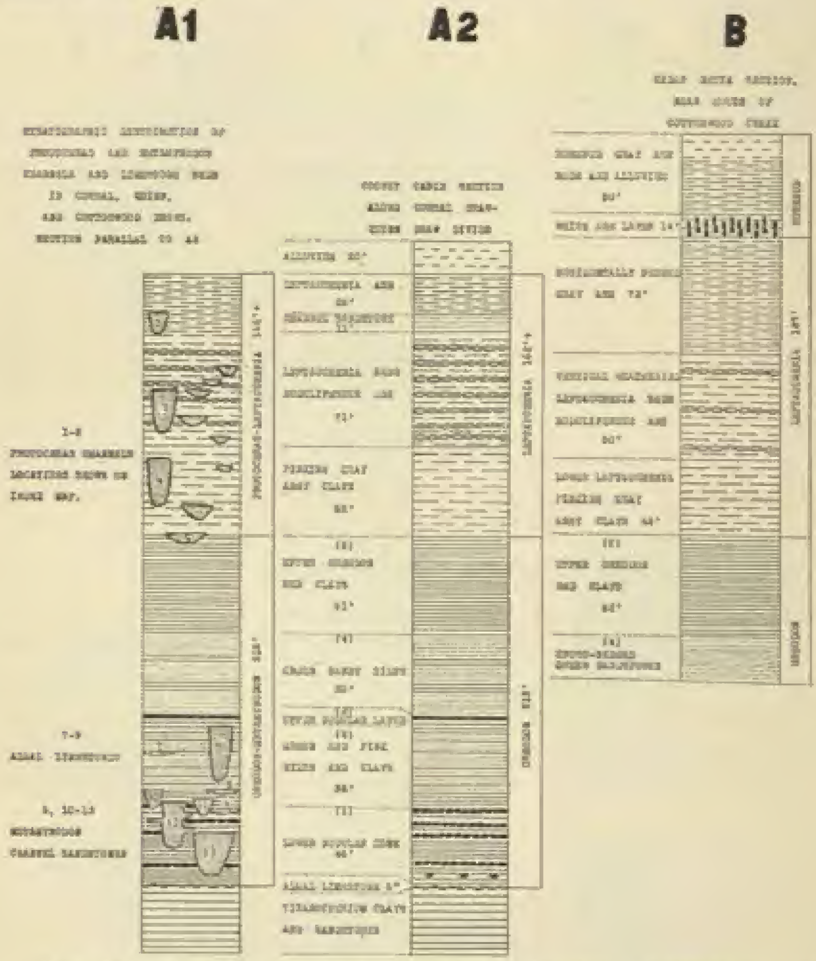
The climate of the time of deposition of the limestone must have been more humid than that at any other period of White River deposition in the area of the Big Badlands, because limestone sheets indicating fresh-water pond deposits were more widespread at this horizon than at any other. There is only a slight mixture of mechanical sediment in the limestone, though small fragments of quartz, biotite, tourmaline, and occasional glass fragments are found. These may have been blown into the pond as a dust.

This limestone sheet is more silicified in some areas than in others, and it was observed that where chalcedony veins were abundant the calcium carbonate was generally replaced by silica, while in areas where chalcedony veins are absent it remained a limestone, often containing only 4 or 5 per cent. of non-calcareous material. This suggests that the silicification was due rather to ground water than to diatoms or other siliceous organisms in the limestone, and that the distribution of silica-rich ground water was irregular rather than universal.

The Oreodon Beds.—The Oreodon beds are widely developed and exposed throughout the western part of the Great Plains province, especially in northeastern Colorado, where they are called the Cedar Creek beds by Matthew; in southeastern Wyoming; and in western Nebraska and South Dakota. Their characters in regions outside the

[29] Proc. of Amer. Phil. Soc., Vol. LX., 1921, Plate VII., Fig. 1.
[30] Ibid., p. 459.

Big Badlands are described by Matthew,[31] Darton,[32] and Todd.[33] Osborn[34] and Matthew[35] have discussed and listed the mammalian fauna, which is one of the largest known from the Tertiary formations of the west.



FIGS. 5–6. Parallel columnar sections of the Oreodon, Leptauchenia, and Lower Rosebud beds in the Big Badlands. (*A–E* on the map, Fig. 1.) Vertical scale 120′ = 1″. Shape of channels in Section A_1 conventionalized.

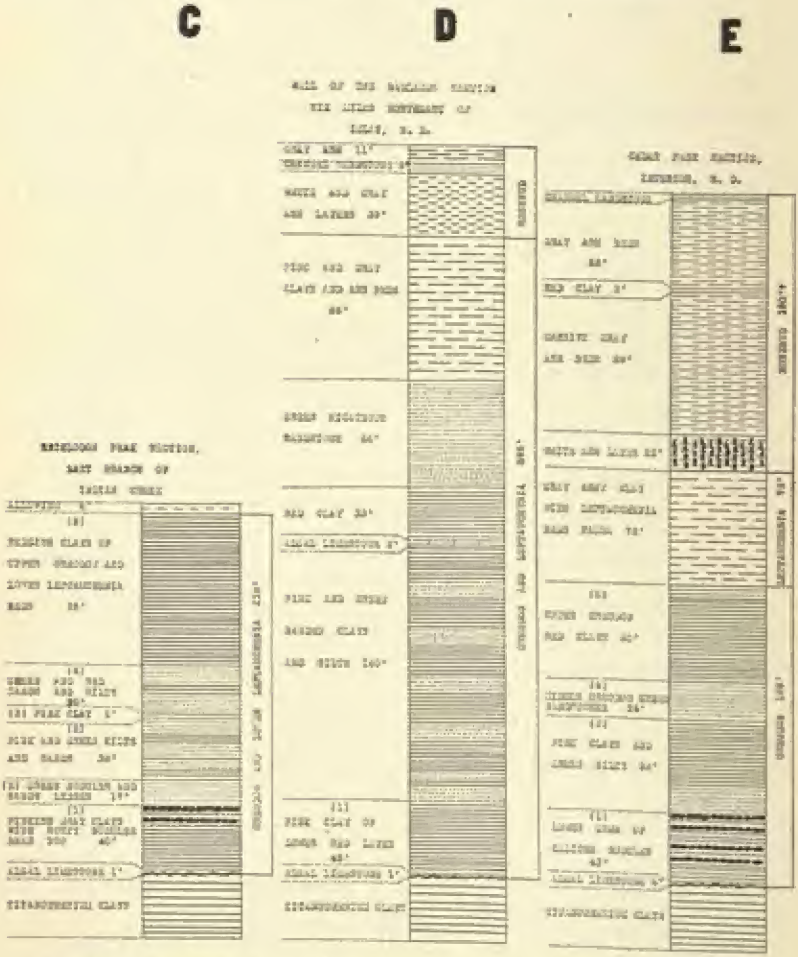
[31] *Mem. Am. Mus. Nat. Hist.*, Vol. 1, Pt. 7, 1901, p. 356. N.E. Colorado.

[32] U. S. G. S. Prof. Paper 17, pp. 38–40; Prof. Paper 32, pp. 169–175; Geol. Atlas, Folios 85, 87, 88, 91, 173; 21st Ann. Rept., Vol. 4, 1900, pp. 542–545.

[33] S. D. Geol. Surv., Bull. No. 2, 1898, pp. 43–68.

[34] U. S. G. S., Bull. 361, pp. 62–63.

As most of the collections made by the Princeton expeditions have come from the two zones of caliche nodules in the lower part of the Oreodon beds, this series has been more widely observed by the writer than any other member of the White River formation.



In Figs. 5 and 6, five columnar sections of the Oreodon beds and parts of the overlying Leptauchenia beds are represented. These sections are distributed as follows (see Index map, Fig. 1): (*A*) at

[85] Ibid., pp. 105–6, 110–11.

the head of Corral Draw to the top of Cooney Table at the divide between Corral, Quinn, and Cottonwood Draws; (*B*) at the Cedar Butte, a high isolated butte about 2 miles northwest of the junction of Cottonwood Creek and White River and about 10 miles south of Sheep Mountain; (*C*) at Entelodon Peak, named by the Princeton party in 1920 because of the numerous skulls and jaws of entelodonts collected in the vicinity of this butte in the lower zone of caliche nodules, near the head of the east branch of Indian Creek, and about 6 miles southwest of Scenic; (*D*) at the western end of the Wall of the Badlands from the valley level to the top of a conspicuous high flat-topped butte capped by a massive layer of channel sandstone—this is 5 or 6 miles northeast of Imlay station; (*E*) the Cedar Pass section of the Wall of the Badlands, about three miles northeast of Interior. The discussion of the Oreodon beds will be based on these sections, as they are quite widely distributed through the area.

The Oreodon beds will, for convenience, be divided into five elements, each of which has sufficiently distinct character and wide lateral extent to entitle it to separate consideration. The divisions are shown in Fig. 4.

(1) *The Lower Nodular or Caliche Zone.*—This is one of the most uniform and widely distributed horizons of the western Tertiaries. It extends with comparatively little change in thickness or lithologic character from the eastern part of the Wall of the Badlands, west and southwest to the head of Cedar Creek, the farthest point in that direction reached by the Princeton parties, and Professor Loomis has informed the writer that it is similarly developed in the Hat Creek basin in northwestern Nebraska and eastern Wyoming, a distance of 150 miles from the Interior section.

It consists of fine silt generally colored a pale pink and when weathered a light rusty brown. It contains fragments of quartz, biotite, muscovite, tourmaline, and more or less weathered feldspar, with a small amount of volcanic glass, which never, however, forms an important constituent of the silt. It has from 10 to 15 per cent. of calcareous cement, and where consolidated into caliche nodules may contain from 25 to 30 per cent.

The lower red layer varies as follows in the section shown: Corral Draw, 46 feet; Indian Creek, 40 feet; northeast of Imlay, 45 feet; and the Cedar Pass section, 43 feet. It is not exposed in the Cedar Butte section in Cottonwood Creek. This is a degree of regularity extremely unusual in continental deposits.

FIG. 4. Divisions of the Oreodon beds recognized in the sections in the Big Badlands. Vertical scale 60′ = 1″.

The nodules are developed along certain definite levels throughout the zone. These levels are generally more abundant toward the top of the red layer. In Indian Creek around Entelodon Peak three levels of nodules occur, all in the upper 6 or 7 feet of the zone. In Corral Draw nodules are developed throughout the red layer at frequent levels to within a foot or so of its base. In Battle Creek Draw nodules are generally absent, and are found only in the vicinity of one or two small channel sandstone deposits. In some sections northeast of Scenic in Sage Creek and Cain Creek basins, and the section

of the Wall of the Badlands northeast of Imlay, no nodules are found, but the total thickness of the red layer is represented by a uniform series of pinkish clays. At Interior caliche nodules are again well developed.

Ward [36] describes the section of the Oreodon beds at Interior and states that there are from 115–135 feet of banded red and green silts of Lower Oreodon age below the Lower Nodular layer. It is not possible to identify all of his field divisions with the writer's section at Interior. He describes an unconformity at the base of the Oreodon beds, and states that in one instance the unconformity was angular with an angle as high as twelve degrees. The beds below the lower red layer in the Interior section have not been carefully studied by the writer. As noted above, at many widely separated localities throughout the Big Badlands the lower red layer was found to vary in thickness between 40 and 46 feet. It always rested upon the Titanotherium beds unconformably, and generally was separated from the latter by a band of fresh-water limestone less than a foot in thickness. Therefore, when the section of the lower red layer at Interior was found to measure 43 feet, a thickness intermediate between the maximum and minimum observed elsewhere in the Big Badlands, and a thin band of algal limestone was observed at its base (on the ranch of W. E. Brown, about 2 miles northeast of Interior), it was assumed by analogy that the beds below this level were of Titanotherium age. No titanotheres were observed in these beds immediately below the Lower Red layer, and therefore the writer has no faunal data for this correlation. The difference between the writer's Interior section and Ward's may be due to (1) a different use of the term Lower Nodular layer; (2) an erosional break within the Titanotherium beds which Dr. Ward has interpreted as the Titanotherium-Oreodon contact; or (3) a great thickening of the Lower Oreodon beds whereby 115 to 135 feet were deposited during the period represented by the Titanotherium-Oreodon gap in the Big Badlands. The latter assumption seems unlikely, inasmuch as the Red layer with a thickness of 45 feet rests upon normal Titanotherium clays in the section of the Wall of the Badlands northeast

[36] Op. cit., pp. 24–26.

of Imlay (*D*) only 20 miles west of this locality. This correlation could probably be settled satisfactorily by observations along the base of the Wall of the Badlands between Imlay and Interior where the lower Oreodon beds are continuously exposed.

The writer's interpretation of the formation of caliche nodules, as outlined in the earlier paper [37] and by Sinclair,[38] is that each horizon of caliche nodules represents an old land surface under conditions suitable for high evaporation. This would probably be a warm and semi-arid climate. The clay at or near the surface of the plain was then cemented by calcareous material, which was deposited by the ground water as it evaporated. Pilgrim [39] describes similar concretionary pseudo-conglomerates which characterize the Lower Siwaliks of Northern India. He suggests two possible origins for them: "(1) formation beneath water, due to segregation of calcareous material implying contemporaneous origin, and (2) formation subsequent to deposition. If the latter is accepted, there are two alternatives: (1) Formation at a much later date in the nature of veins and pockets produced by infiltration. This would not account for thin bands widely distributed and should be absent from adjacent sandstones and clays. (2) The entire concretionary structure of a particular band was produced in it before the deposition of layers above it. The only way in which this can have taken place would be if long periods of entire or almost entire cessation of flood alternated with periods during which floods were of constant, probably annual occurrence. During periods of rest large portions of land surface must have remained almost dry and have been subjected to atmospheric forces, capillarity and evaporation, such as determine the formation of kankar in the plains of Bengal at the present day. The concretionary band, therefore, represents a soil layer, which is of greater or lesser thickness, according to whether it has remained subject to atmospheric influences for a longer or shorter time. Since it may be concluded that the layers of sediment left exposed during each of the periods of desiccation would vary in their lithological

[37] Proc. Amer. Philos. Soc., Vol. LXI., 1922, pp. 195–197.

[38] Proc. Amer. Philos. Soc., Vol. LX., 1921, pp. 462–465.

[39] Records of Geol. Survey of India, Vol. XLII., Pt. 4, 1913.

character, being sometimes sand and sometimes clay, we should expect the subsequent character of the concretionary band to vary also. This is in fact the case. The color and material of the matrix is very different in different bands, although the nature of the concretionary action in general appears to have been the same." [40] He goes on to suggest that the great frequency of concretionary layers in the Lower Siwaliks, implying numerous halts in deposition, may mean that twice as much time is demanded for their deposition as for that of the Middle Siwaliks in which there is not much evidence of halts in deposition. A close parallel to the caliche layers in the White River formation is here presented and an explanation almost identical with that adopted for South Dakota conditions has been reached. Pilgrim's suggestion of the lengthening of the total period of deposition is important, and may imply a length of time out of proportion to their thickness for the Lower Oreodon beds.

The irregularity of the development of the caliche nodules both in the Oreodon beds and the Leptauchenia beds presently to be mentioned is a problem for solution. As mentioned above, over wide areas such as most of the basin of Cain Creek northeast of Scenic nodules are practically absent in the Red layer, the total thickness being represented by pink clay. There are no channel sandstones observed in the Lower Oreodon beds in this area. Near the head of Battle Creek Canyon southwest of Scenic, after prospecting several miles of exposures of the Red layer where nodules were not developed, a small area with a rich exposure of caliche nodules was found. Within a hundred yards of this outcrop was the only stream channel which had been seen in the Lower Oreodon beds in this whole creek basin. The very rich development of caliche ash nodules around the Protoceras channels at the head of Corral Draw (described below) and their absence elsewhere in the Leptauchenia beds also suggests a connection between stream channels and caliche nodule development. It is probable that the absence of caliche nodules away from the stream channels is due to the fact that the water table is further from the surface, and therefore the evaporation of water drawn to the sur-

[40] Ibid.

face by capillarity and the deposition of $CaCO_3$ as a cement of the clays is correspondingly less. The caliche beds are only well developed in the vicinity (within a quarter to half a mile) of the courses of the old stream channels where the amount of ground water and its dissolved carbonates would be greater.

It has recently been observed that most of the clays of the Lower Oreodon beds, as well as the caliche nodules, are composed of small rounded balls or pellets of clay varying from the size of wheat grains to that of a large hickory nut. These are enclosed in a matrix of clay usually slightly different in color. They evidently are formed of small fragments derived from the land surface of the bed below, plucked by advancing flood waters and incorporated in the silts deposited by the flood upon its subsiding. The rounded form of the pellets is evidently due to the rolling and may have resulted in some rounding off of angular faces and accretion of clay picked up while the pellets were moving. As these do not show a concentric development, the latter does not seem to have been as important a factor as the former. The pellets may be easily detected by the unaided eye and sometimes weather out as hard rounded balls about the size of hickory nuts.

Plate III., Fig. 2, shows such a pellet conglomerate from the Lower Nodular layer in Battle Creek Draw. Clay balls are found in the bottom of many badland draws today. These are of much larger size and somewhat different origin. They average from 5 inches to a foot in diameter and are formed mainly by accretion. Extraneous material, such as fragments of chalcedony veins and small pebbles, are found in these masses as well as clay. They may be easily broken up by slight pressure. There is an excellent illustration of these modern clay balls in Dr. O'Harra's Badland report.[41] The presence of clay balls abundantly distributed through the badland clays is one of the most definite proofs of the sheet-flood transportation of the clays containing them, for the settlement of finely divided clay in lake basins does not produce these structures.

It may be well here to review a few of the other evidences found in the zones of caliche nodules in support of the flood-plain deposition

[41] S. D. School of Mines, Bull. No. 13, Plate 71*A*.

FIG. 1. Articulated skeleton of *Oreodon culbertsoni periculorum* in death pose. Lower concretionary zone, Oreodon beds, Bear Creek basin.

FIG. 2. Clay pellet conglomerate from the Lower Nodular layer in Battle Creek Draw. Part of a large nodule inclosing two individuals of the sabre-tooth tiger *Hoplophoneus primævus*. No magnification.

FIG. 1. Upper Nodular layer, Oreodon beds, Corral Draw basin, about one mile southwest of Cottonwood Pass.

FIG. 2. Lower Nodular layer, Oreodon beds, in Indian Creek basin near the Big Corral Draw divide.

FIG. 1. In Corral Draw, south of Cottonwood Pass. Section of the Oreodon beds numbered to correspond with A1 and A2, Text Fig. 5, and also with Text Figs. 4 and 9A.

FIG. 2. Main head branch of Corral Draw cutting a Metamynodon channel (No. 12, Text Figs. 5A1 and 7). Protoceras channel to right of central butte.

of the sediments. Sinclair [42] has discussed some of these in an earlier paper.

(1) Turtles are very abundant in the red layer. Frequently the fossilized carapaces are found in all sorts of positions (bottom side up, or even on edge), and the hollow central cavities are filled with clay usually containing small clay pellets of the type above described. These turtles are all land tortoises, mostly of the species *Stylemys nebrascensis*. The only aquatic turtles collected from the badlands are from the stream channels.

(2) It was mentioned above in connection with algal pond deposits that fresh-water gastropods were found abundantly in the limestones of pond origin through the Oreodon and Titanotherium beds. In the upper and lower red Oreodon clays, and the Leptauchenia nodular clays at Interior, land snails have been found fossilized in caliche nodules. These have been specifically determined by Dr. Pillsbry as follows: *Helix leidyi* (Meek and Hayden) [43] a land snail, in the Lower Red layer and Leptauchenia clays, and *Lymnæa shumardi* (Meek and Hayden) probably a fresh-water gastropod, in the upper read clays.

(3) Mouse-gnawed bones are frequently found in the badland clays.

(4) In the preparation of a *Cœnopus* skull many casts of insect larval burrows were found within and around the skull, suggesting that it had lain on the surface for some time before burial, and the flesh had been devoured by the scavenging insects which subsequently burrowed for pupation in the mud investing the skull. Similar larval burrows are found isolated in the clays and not associated with skulls or other bones.

(5) Coprolites of carnivorous animals are abundantly preserved in the badland clays. They are specially numerous around skulls or partial skeletons of herbivorous animals such as *Oreodons* and *Entelodons*, but do not represent the intestinal contents of these animals, since they often show fragments of bone. Many of the coprolites have not been softened and show distinctly the impress of the anal muscles. It is known that modern carnivores have a habit of sniffing

[42] Proc. of Amer. Phil. Soc., Vol. LX., 1921, pp. 461–462.

[43] U. S. Geol. Surv. of Territories, Vol. IX., Meek, pp. 598–604.

around inedible substances and defecating disgustedly thereon. Hatcher, collecting in the western badlands, once had the experience of having several packages of fossils torn open by a coyote in his absence, and fecal material dropped on each package.

(6) At many places throughout the outcrops of the nodular layer fragmentary remains of several different kinds of animals are found close together, often within an area ten feet or less in diameter. For example, in the valley of the north branch of Indian Creek skull and jaw fragments of *Hoplophoneus, Hyænodon, Oreodon, Leptomeryx, Perchœrus,* and *Mesohippus* were all found close together. These bone piles probably were accumulated by being dragged to their present positions by carnivorous animals. In the locality referred to there may have been the lair of some Oligocene sabre-toothed tiger or *Hyænodon.*

(7) Occasionally skeletons are exposed on the plain in death pose. "In 1920 an articulated *Oreodon* skeleton collected by the Princeton expedition had the head and neck bent back in a manner frequently observable in the more or less dried-up carcasses of sheep killed in storms." [44] This skeleton is shown in Plate III., Fig. 1.

(8) In 1922, in Battle Creek Draw, two skeletons of sabre-toothed tigers (*Hoplophoneus*) were found in the Lower Red layer in Battle Creek Draw in a very restricted area, about one yard in diameter. No sabres were found in the skulls, but all four of the sabres were found separately associated with toe bones, vertebræ, and other skeletal parts. These skeletons were probably embedded in some local depression.

(9) Articulated skulls and jaws of Oreodons detached from any other skeletal remains are very common in the badland clays. These heads may have been dragged off by carnivorous animals from the remainder of the skeleton. A large enteledont skull collected in Indian Creek (Entelodon Peak) in 1920 had the cervical vertebræ in articulation, and a few other fragments of bones were found in the vicinity, but none of the large limb bones of the entelodont were visible. This would hardly have been the case if the head had not been moved away from the carcass, as the limb bones of a large entelodont are massive and would almost certainly be preserved.

[44] Sinclair, op. cit., p. 462.

The above facts observed in the field can all be easily interpreted by assuming a level plain subject to periodic flooding, but are very hard to explain if the deposition is held to be lacustrine.

(2) *Lower Oreodon Banded Silts.*—Division (2) of the Oreodon beds includes a sequence of banded pink and green silts. In some sections, as in Battle Creek Draw, the green beds predominate and are locally quite sandy. In the section in Corral Draw greenish or grayish silts predominate, but there are several thin bands of reddish clay running through it. This division is not exposed at the Cedar Butte near the mouth of Cottonwood Creek (Section B), and its upper limit is not differentiated in the section northeast of Imlay, as the Upper Nodular layer which ordinarily bounds it above is absent there. Its thickness is 55 feet in Corral Draw and Indian Creek and 58 feet at the Cedar Pass section near Interior. Plate V., Fig. 1, shows the development of this zone in Corral Draw, near Cottonwood Pass. Caliche nodules are absent from this division, though the greenish silt beds often weather in rounded forms, resembling the caliche nodules in size and shape. In Bear Creek basin, five miles south of Scenic, two or three beds of these greenish silt nodules occur just above the upper limit of the Lower zone of caliche nodules.

Metamynodon Channel Sandstones.—Here and there throughout the Big Badlands lens-shaped masses of sandstone and conglomerate, characterized by the presence of the large aquatic rhinoceros *Metamynodon*, cut the normal sequence of clays and caliche nodules in the Lower Oreodon beds (Pl. V., Fig. 2). These channels are sometimes represented only by small masses of fine-grained micaceous sandstone, as in the north branch of Indian Creek, adjacent to Hart Table, while in the upper part of Corral Draw, Cottonwood Creek, Indian Creek, and Quinn Draw these channels occur more frequently than elsewhere in the badlands and are represented by thicker and coarser sandstones. Here they commonly consist of alternations of coarse conglomeratic beds with finer micaceous sandstones, which can often be followed for a mile or more. As the sandstones are much harder rocks than the adjacent clays, their massive conglomeratic beds stand up from 15 to 50 feet above the levels of the adjacent creek valleys. The columnar section *A*1, Fig. 5, shows the stratigraphic positions of some

of these channels in the Lower Oreodon beds, and Fig. 1 shows the geographical distribution of some of the lenses of channel sandstone in the Corral Draw area. It will be observed that the channels are cut both in the Lower Nodular zone and in the clays above it, but more abundantly in the latter. If a channel sandstone dies out laterally at a level at which caliche nodules are developed, these are locally absent for 100 to 200 feet on either side of the channel. However, in some cases a channel cuts a level of nodules formed at an earlier time than the channel. Then the nodules may be developed to the very edge of the channel, where they terminate abruptly against the sandstone.

The channels vary considerably in width. Channel No. 13 of Sec. *A*1, Fig. 5, is about 100 yards in average width and has cut down nearly into the Titanotherium beds, while Channel No. 11 is narrow and less than 50 feet in average width. These channels probably represent braided streams in which one main river was divided into several narrow channels by frequent islands. In one section in Indian Creek and two in Corral Draw the channels have been observed to pass laterally into algal limestones or to rest on algal deposits. Sinclair [45] has described this phenomenon in Indian Creek. The mineral composition of the Metamynodon channels was discussed by the writer in the earlier paper, and no new data have been accumulated.

Algal limestone deposits occur more frequently in Division (2) than elsewhere in the Oreodon beds with the exception of the discontinuous sheet at their basal contact. Section *A*1, Fig. 5, shows the vertical distribution of the algal beds in the Corral-Quinn-Battle Creek Draw area, and Fig. 7 shows the geographical locations of the ponds in which they were formed. In Plate II., Fig. 1, a portion of the edge of Cooney Table in Battle Creek Draw is seen with two limestone beds between the Upper nodular layer and the Lower zone of caliche nodules. They are 20 and 40 feet, respectively, below the Upper nodular layer. An algal pond deposit (No. 9 in Fig. 1 and Sec. *A*1) near the Corral-Indian Creek divide 1 mile northeast of Cottonwood Pass is just below the top of the Red layer. The lower limestone bed shown in the photograph is very local (not over 100

[45] Op. cit., pp. 460–461.

yards in diameter), but the upper limestone bed is persistent as a thin algal-ball level over several square miles on the southern side of Quinn Draw basin, where it usually forms a pronounced bench. The

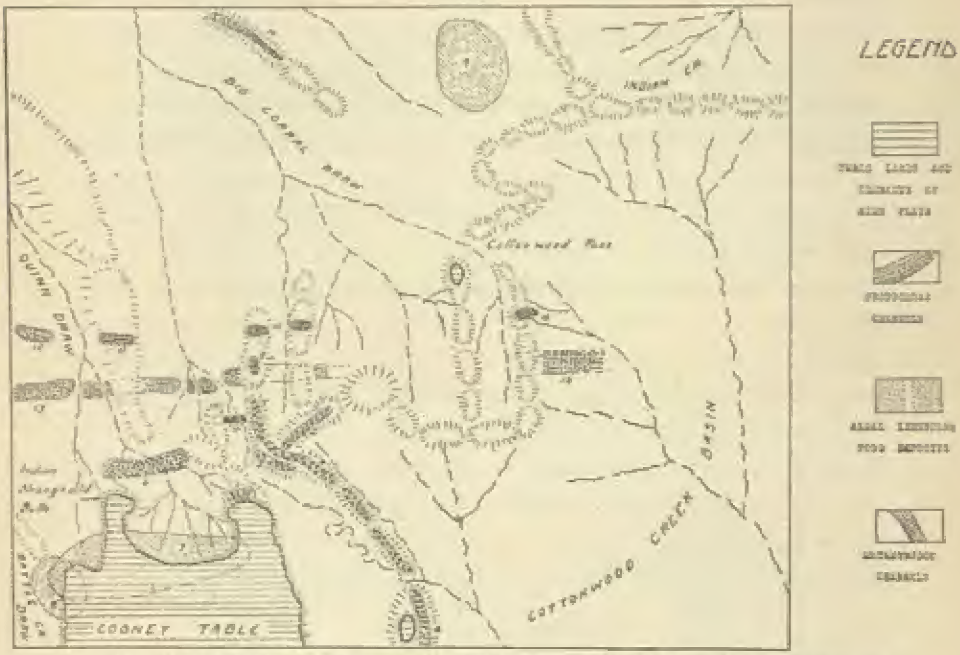


FIG. 7. Sketch map of a portion of the basins of Battle Creek, Quinn, and Big Corral Draws, Indian Creek, and Cottonwood Creek, in the Big Badlands, showing the distribution of Metamynodon and Protoceras channel sandstones, and algal limestone pond deposits in the Lower Oreodon beds. Adapted from map of the Pine Ridge Indian Reservation (Dept. of the Interior, Office of Indian Affairs, 1914). Scale 1/42240. (3 miles = 2".)

algal balls are flattened oval-shaped and about 6 inches in length and 2 to 4 inches in thickness. In these are found abundant fresh-water pond invertebrates, especially *Planorbis* and Cyprid crustaceans. They sometimes have hollow centers and generally a concentric structure. Sometimes the growth started around a clay pellet or mammalian tooth or bone, or (as in the Titanotherium beds in the north branch of Indian Creek) around a *Unio* shell, and continued outward growth until the drying up of the pond. The algal-ball levels may represent shallow ponds or damp meadows of shorter duration than

those which have formed a solid sheet of limestone. The fauna seems to have been essentially the same.

(3) *The Upper Nodular Layer.*—This is a single horizon of caliche nodules which is very widespread in the Big Badlands. It is developed from the vicinity of Arnold's ranch (see map, Fig. 1) on the east, westward about 30 miles to the headwaters of Cedar Creek, the farthest point to the west reached by the Princeton expeditions. Where nodules are not present at this horizon it is usually represented by a band of pinkish clay. This is the case in the Entelodon Peak section and adjacent portions of Indian Creek. It has not been recognized in the Bear Creek sections east of Scenic, nor at Interior, but is an excellent horizon marker throughout the Corral-Quinn-Cottonwood-Battle Creek Draw area. Plate IV., Fig. 1, illustrates a fine development of nodules at this horizon in Corral Draw basin about one mile southwest of Cottonwood Pass. These nodules contain quite abundant vertebrate remains, as do those of the Lower zone of caliche nodules. Osborn and Wortman,[46] speaking of *Oreodon bullatus,* state: "There is a single skull in our collection which was obtained from the second nodular layer, from 75 to 100 feet above the 'Red Layer' of the 'Oreodon bed.'" This is evidently a reference to the Upper Nodular layer as here defined. Interruptions of the Upper Nodular layer by channels or algal limestones have not been observed, and doubtless it represents a short recurrence of semi-arid climate similar to that prevailing during the deposition of the lower zone of caliche nodules. The average thickness of this layer is about one foot. Above it two feet of gray unconsolidated clay resembling the spongy Titanotherium clays usually are found, then the green sandy silts of division (4) of the Oreodon beds.

(4) *Middle Oreodon Green Sandstones.*—This division is characterized throughout the Big Badlands by a green or gray-green color, and unusually sandy nature. It is at the base of the section at the Cedar Butte (Sec. *B,* Fig. 5) and there and in the valleys of Battle Creek Draw and Battle Creek Canyon to the west is a massive green sandstone. Plate I., Fig. 1, shows well the development of this zone along the edge of Cooney Table in Battle Creek Draw. Its thickness

[46] *Bull. Amer. Mus. Nat. Hist.,* 1894, Vol. VI., p. 218.

in Corral Draw is 55 feet (Sec. *A2*), while at Interior it is represented by 24 feet of greenish silts (Sec. *E*). Although these form continuous beds of sandstone, they often weather into rounded forms resembling in shape and size the caliche nodules, hence Ward [47] describes this bed as the Upper Nodular sandstone, and the writer in the earlier paper [48] referred to it as the Upper zone of nodules, more generally green than rusty. Fossils are rarely observed in this division, although turtles and fragmentary mammalian remains are occasionally found.

(5) *Upper Oreodon Red Clays.*—Above the zone of greenish sands and silts (4) there is almost always an abrupt change of phase to a red clay resembling in character that of the Lower Red layer where nodules are not developed in it. Microscopic examination shows that it differs from the Lower Oreodon clays in having a notably higher content of volcanic glass and pumice fragments. It is generally exposed in steep walls, as the Leptauchenia beds overlying are usually more resistant to weathering than this division. Plate I., Fig. 1, shows clearly the change from divisions (4) to (5) in the Battle Creek Draw section, as well as the light-colored band which at present is used to define the contact between the Oreodon and Leptauchenia beds. This division of the Oreodon beds has a thickness of 62 feet at the Cedar Butte in Cottonwood Creek, 61 feet at the head of Corral Draw, and 60 feet at the Cedar Pass section near Interior, another remarkable example of uniformity over wide areas. In the Entelodon Peak section the upper limit of this division is not defined, and the 95 feet at the top of the section probably include part of the lower division of the Leptauchenia beds. In the section at the head of Corral Draw the lowest Protoceras channels cut down into this division about 10 or 15 feet.

The section of the Wall of the Badlands, northeast of Imlay, can not be clearly interpreted. The visit made here was brief and the only divisions clearly correlated with the other exposures of the Oreodon and Leptauchenia beds were the Lower Nodular layer and the White Ash (defined below). The beds between were all alternations of pink and green silts, with one bed of massive sandstone 66

[47] Op. cit., pp. 27–28.

[48] Proc. of Amer. Philos. Soc., Vol. LXI., 1922, p. 187.

feet thick, at a position corresponding to the upper red clays of the Oreodon beds. The relations of this section to others of the White River formations could be worked out by more detailed study, but the section is presented here principally to show the persistence of the limestone at the base of the Oreodon beds, the Lower Red layer, and the White Ash.

The Leptauchenia-Protoceras Beds.—The Leptauchenia beds are less widely recognized in the Great Plains region than are the underlying Oreodon beds. They are included with the Oreodon beds in the Brulé clays of Darton.[49] Matthew recognizes them in northeastern Colorado, and names them the lower "Martin Canyon" beds.[50] Osborn [51] gives the correlation and distinctive faunal characteristics of the deposits of this age and Matthew [52] has published a list of the known fauna from this zone.

The Leptauchenia beds in the Big Badlands may be clearly separated into three divisions, but these divisions have not yet been recognized in the Interior section at Cedar Pass. It is very difficult to decide where the base of the Leptauchenia beds should be drawn, as there is no sudden change in the lithologic character of the sediments such as that which initiates Oreodon beds deposition. As the Leptauchenia-Protoceras zone is a faunal division, the contact has been tentatively placed by the writer at the level along which the lowest channel with a *Protoceras* and *Leptauchenia* fauna dies out laterally. This is a light-weathering band which can easily be traced for many miles in the Big Badlands. This plane of division differs from that in the section published in the previous paper in that it transfers to the Lower Leptauchenia beds 50 feet of reddish clays there included in the Oreodon division. The channel which is situated lowest stratigraphically had not been seen when the section published last year was measured, and there was then no reason for believing that the Protoceras-Leptauchenia fauna extended lower than the level of the lowest observed channel carrying this fauna.

[49] U. S. G. S., Prof. Paper 32, pp. 170–175.

[50] *Mem. Am. Mus. Nat. Hist.*, Vol. 1, Pt. 7, 1901, pp. 353–447.

[51] U. S. G. S., Bull. 361, pp. 53–64.

[52] Ibid., pp. 106–111.

The relations between these sections as now revised is shown diagrammatically in Fig. 8.

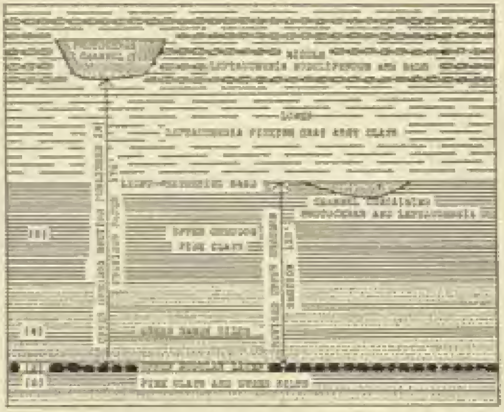


Fig. 8. Sketch showing the revision of the section of the Upper Oreodon beds and the stratigraphic position of the Leptauchenia-Oreodon contact at the head of Big Corral Draw, Big Badlands. Vertical scale 120′ = 1″.

Division (1).—The lowest division of the Leptauchenia beds in the Big Badlands is a reddish or gray clay with a considerable amount of volcanic glass and pumice fragments. This does not differ notably in its type of weathering from the upper division of the Oreodon beds (5) as here defined. The plane of contact with the Oreodon clays, as mentioned above, is a light-weathering band which is clearly recognizable over a large portion of the Big Badlands, and is plainly visible in the accompanying photograph, Plate I., Fig. 1, a section of the edge of Cooney Table in Battle Creek Draw. The lowest Protoceras channel dies out laterally at this level and cuts 25 feet below it into the clays of the Upper Oreodon beds. The thickness of this lower division of the Leptauchenia beds is 45 feet in the Cedar Butte section and 55 feet in the Cooney Table section, Corral Draw.

Division (2).—The middle division of the Leptauchenia is best exposed along the divide between Big Corral Draw and Cottonwood Creek in the Big Badlands and along the adjacent edge of Cooney Table. It is characterized by the development of levels of caliche nodules resembling in appearance those of the Lower Oreodon beds, but not containing mud pellets. Analysis of one of the caliche nodules

showed it to contain 38 per cent. of calcareous cementing material. The silt consisted mainly of quartz, volcanic glass, and biotite, the glass amounting to 50 per cent. or more of the total. The stream channels (Pl. VI., Figs. 1 and 2) carrying a *Protoceras* fauna are very abundant in this division of the Leptauchenia beds and are found at a variety of levels, often initiated by a coarse conglomeratic sandstone, followed by a fine-grained green micaceous sandstone, and capped by another ledge of coarse massive sandstone. The caliche nodules are developed most strongly in the vicinity of the stream channels and at a distance of three or four miles from the nearest Protoceras channel they are only occasionally seen. These nodules represent the recurrence of a period of greater aridity (but not desert conditions) when the lime was deposited by evaporation of ground water drawn to the surface by capillarity. Their greater abundance in the immediate proximity of stream channels suggests that the ground was there more completely saturated with water than elsewhere. The waters of the streams draining from the Black Hills should have a fairly high calcareous content, for they cross the outcrops of the thick Carboniferous limestone, which averages nearly 500 feet in the southern Black Hills. The thickness of this middle division of the Leptauchenia beds is 65 feet in the Cedar Butte section. On the edge of Cooney Table where the section was measured the upper limit of these nodular ash beds was obscured by a Protoceras channel.

The Protoceras channels are commonly developed through the Lower and Middle divisions of the Leptauchenia beds, and as stated above, at one point, cut down into the upper reddish clays of the Oreodon beds. They are principally developed in the valleys of Corral and Cottonwood Creeks in the Big Badlands, and constitute a pronounced topographic feature at the head of the central and western branches of Corral Draw, about 2½ to 3 miles southwest of Cottonwood Pass. Here the channels cap the divide between White and Cheyenne River drainage for about half a mile, and by reason of their massive character remain supported on vertical pillars of clay, sometimes 200 feet or more above the adjacent draws. These channels are distributed vertically through about 130 feet of beds and the

FIG. 1. Several levels of Protoceras channels, overlain by the nodule-bearing Leptauchenia ash beds, along the Corral Draw-Cottonwood Creek divide.

FIG. 2. Looking west along the Corral Draw-Cottonwood Creek divide, showing a probable meander in the course of a Protoceras channel.

Base of White Ash

FIG. 1. White Ash layer with underlying Leptauchenia beds of Division (3) on the top of the Cedar Butte, 12 miles south of Sheep Mountain.

FIG. 2. Looking southeastward from the top of Sheep Mountain toward Arnold's ranch, showing, in the foreground, Division (3) of the Leptauchenia beds.

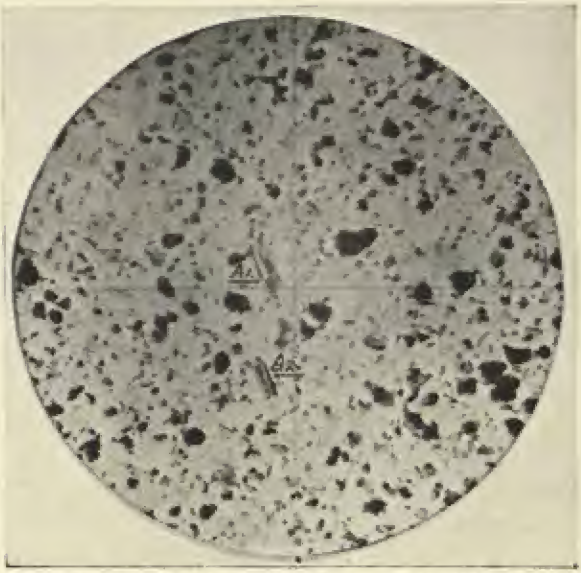


FIG. 1. Microphotograph of volcanic ash from the White Ash layer, Cedar Pass section, Interior, S. D., showing two large pumice grains (A1 and A2) with capillary tubes. Most of the smaller grains are angular fragments of volcanic glass.

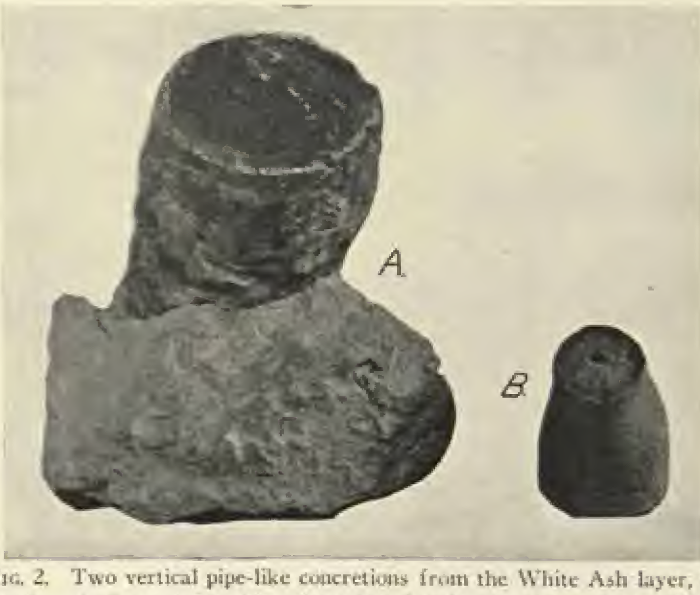


FIG. 2. Two vertical pipe-like concretions from the White Ash layer, Sheep Mountain. A. Large concretion about 2 inches in diameter and 6 to 8 inches in length, filled with darker-colored material than that on the margin of the concretion, where there is a lighter border. B. A smaller concretion with a hollow central tube which is lined with minute crystals of zeolites.

stratigraphic positions of several of the more pronounced massive lenses of sandstones is given in Columnar section *A*1, Fig. 5. The highest channel (No. 1) is situated on the edge of Cooney Table at the Quinn-Corral Draw divide. Plate VI., Fig. 1, is a photograph of a heavy channel sandstone 25 feet in thickness, which for a distance of nearly a quarter of a mile caps the Corral Draw-Cottonwood Creek divide. Several levels of caliche nodules of the middle division of the Leptauchenia beds are visible above the channels. On the map, Fig. 7, the distribution of Protoceras channel sandstone outcrops in Corral Draw and Cottonwood Creek is shown. The general direction of the Protoceras channels from the Corral-Cottonwood divide for three or four miles into Cottonwood Creek is about S. 60° E., which is also the direction of maximum initial dip in the sediments, and hence probably the direction of the original graded slope of White River time. Protoceras channels have also been observed at Interior and are described and figured by Ward.[53]

One Protoceras channel sandstone from Cottonwood Creek, analyzed mechanically, contained 17.5 per cent. of heavy minerals (gravity greater than 2.95), of which over 90 per cent. were garnets. Pebbles of mica schist and quartz schist, tourmaline and staurolite, also occur in this sample, and its grains are of various sizes, showing poor sorting. Frequently large fragments derived from the Leptauchenia ash beds are found in the channel sandstones and they may constitute a high percentage of the material locally. At one point in Cottonwood Creek a layer of brownish pebbles, which, upon analysis, were found to be caliche nodules from the middle division of the Leptauchenia beds, was found in the middle of a section of about 10 feet of fine-grained greenish micaceous sands. This shows that the caliche nodules had been formed and were subject to erosion at the time that this sandstone was deposited. The abundant deposition of this material derived from the adjacent flood plain was probably due to local cloudbursts of unusual severity.

An interesting parallel to the White River sandstones is offered by those of the Siwaliks, of late Tertiary age, which were deposited by sediment-laden streams from the Himalayas when they spread out

[53] Op. cit., p. 30 (Bed F), and Plate XV.

on the Indo-Gangetic plain. McMahon[54] notes that the "Siwalik sandstones contain largely quartz, muscovite, garnet, schorl tourmaline, and some weathered feldspar . . . and some limestone pebbles." He believes that most of the material is derived from the Dalhousie granite of early Tertiary age. The mineral aggregate described here is almost the same as that found in the sandstones of the White River, but volcanic glass does not seem to have been a factor in the Siwalik deposits.

Division (*3*).—The upper division of the Leptauchenia beds is a massive, more thoroughly cemented sequence, which weathers with an irregular surface due to the presence of a succession of harder and softer beds. The stratification is much more apparent than in the clays below, with cross-bedding sometimes developed. No Protoceras channels have been observed cutting these beds. The cause of the marked stratification of this series is not apparent to the writer unless it represents rapid oscillations of climate. Exposures occur only on the edges of Sheep Mountain (Plate VII., Fig. 2) and in the Cedar Butte section (Plate VII., Fig. 1), where there is a thickness of 72 feet. In Corral Draw it has been cut out by the alluvium on top of Cooney Table. It gives rise to the pronounced organ-pipe type of weathering which is so splendidly exhibited on Sheep Mountain, and is also exposed along the south side of White River below the White Ash layer (defined below), but this section has not been visited by the recent Princeton expeditions. Volcanic glass and pumice are very abundant in this division, probably averaging more than 50 per cent. of its clastic material.

In comparing the sections in the Big Badlands with that at Interior, Jackson County, about 60 miles to the northeast, it will be at once noticed that the whole thickness of the Leptauchenia beds has been greatly reduced. The total thickness of the Leptauchenia beds at Interior is 72 feet, where it is bounded at the base by the Upper Oreodon reddish clays, from which it is separated by a light-weathering band like that exposed in the Big Badlands at the contact, and, at the top, by the White Ash layer. The Interior section, as previously published, included in the Upper Oreodon beds all of the

[54] Records of Geol. Survey of India, Vol. XVI., Pt. 4, 1893.

upper clays to the base of the White Ash layer. The presence of *Leptauchenia* 50 feet below the White Ash layer had not been observed at that time, nor had the persistence of the latter and its value for correlation been determined. The revised Cedar Pass section is shown in Fig. 6, *E*.

It is remarkable that while the upper member of the Oreodon clays persists with practically no thinning from the Big Badlands to the Interior section, the Leptauchenia beds thin from about 170 feet at the Cedar Butte to 72 feet at Interior, the thickness of the upper member alone in the Big Badlands. It is interesting to note that Ward [55] divides the series from the top of the Oreodon beds to the White Ash layer into three divisions which he describes successively as (*a*) "a gray massive sandy shale with scattered poorly defined sandstone nodules, (*b*) a light gray, fine-textured sandstone noticeable for its pronounced bedding, and (*c*) a massive fine sandy shale resembling (*a*)." In view of the rapid thinning of the Leptauchenia beds away from their source of material it would be interesting to know whether all of its members persisted or whether one or more of them were missing. The lower member in the Big Badlands seems to resemble (*a*) of the Interior section and the upper member of the Big Badlands seems more like (*b*) of the Interior section, as a pronounced stratification is a characteristic of both. Ward does not mention the presence of *Leptauchenia* at Interior, but they were found quite abundantly on either side of the road running through Cedar Pass about 200 yards north of the top of the pass on each of our three visits to this section. They seem to be most abundant in his division (*b*). *Miohippus* and *Eporeodon major*, both typical fossils of Leptauchenia age, were also found here.

At one or two localities in Cottonwood Creek irregular thin beds of almost pure white ash were observed in the Leptauchenia clays. The thickness of these beds was not greater than one or two inches. These are probably remnants of light ash falls preserved locally under favorable conditions.

The White Ash Layer.—The White Ash layer is one of the most persistent and interesting elements in the White River area. It rests

[55] Op. cit., pp. 29–30.

upon the upper division of the Leptauchenia beds and is clearly recognizable at all points through the region where the higher beds are exposed, the best sections being on top of Sheep Mountain, the Cedar Butte near the mouth of Cottonwood Creek, the Cedar Pass section at Interior, and the western part of the Wall of the Badlands five miles northeast of Imlay. It has in all sections a thickness of from 15 to 25 feet. Its base is clearly defined, but its upper margin is so nearly like the overlying grayish ash beds that it is hard to determine its upper limit close at hand. From a distance of a mile or so its lightness of color and greater resistance to weathering than the beds above and below cause it to stand out prominently as a distinct unit. It is exposed on the south side of White River for several miles east of the mouth of Porcupine Creek along the badland edge of the high plain south of the river. In nearly all the sections described by Darton in the western part of Nebraska [56] and in the Goshen Hole area of eastern Wyoming [57] there are either one or two ash beds in the upper part of the Brulé clays. These are spaced from 50 to 200 feet below what he terms the top of the Brulé clays. Matthew [58] writes: "A bed of volcanic ash lies near the top of the formation" (Rosebud) in the section of Porcupine Creek. It is possible that one of the two ash beds of western Nebraska corresponds to the latter and the other to the White Ash layer of the Big Badlands sections. The thicknesses of the ash layers mentioned by Darton vary from six to twelve feet.

Matthew suggested the White Ash layer south of White River as the base of the Rosebud formation in his type section on Porcupine Creek. He places the Rosebud formation in the Lower Miocene, because [59] "*Parahippus* which shows a decided advance over *Miohippus* in feet, though near it in teeth, and evidently an invading type appears in the Rosebud." This correlation is only tentative and may be changed by further field work.

The following section and description [60] of the occurrence of Ter-

[56] U. S. G. S., Prof. Paper No. 17, pp. 37–40; also plates and figures.

[57] U. S. G. S., Geol. Atlas of the U. S., Hartville Folio (No. 91), Columnar Section Sheet, Sections 2 and 4.

[58] *Bull. Am. Mus. Nat. Hist.*, Vol. 23, p. 173.

[59] Personal communication.

[60] Darton. U. S. G. S., Prof. Paper No. 51, pp. 67–70.

tiary ash in the Big Horn Mountains east of Canyon Creek is valuable, as it supports the theory that the White River ash was derived from regions to the west of the Black Hills:

"Sandy clay soil	6 feet
Gravel of crystalline rock with lenses of volcanic ash near the base, and with occasional boulders up to two feet in diameter	60 feet
Volcanic ash, arkose, fragments of igneous rock, etc., indistinctly stratified	73 feet
Conglomerate cemented by lime carbonate, boulders up to 4 ft. in diameter and generally well rounded	22 feet

The amount of volcanic ash in this section is large, and it appears to have been laid down by water, although some of the finer portions may be wind blown. The nearest eruptions from which it could have been derived, so far as known, are in the great volcanic area west of the Bighorn Basin. As most of these eruptions occurred in Tertiary times and as volcanic ash is generally characteristic of the Tertiary beds in the Black Hills and farther east, the Bighorn deposits are provisionally referred to this age. . . . The conglomerate with lime matrix and volcanic ash appear at other outlying localities. . . . Evidently the deposits originally extended over a broad area east of the mountains as shown by the widely scattered remnants . . . and since their deposition there has been extensive erosion to the present low level of the plains."

The very wide distribution of volcanic ash of Upper Oligocene and Lower Miocene age is apparent from the above data. The Bighorn section is not dated, but it may well be of White River age, as outliers of the White River are found in pockets in the pre-Cambrian rocks of the Black Hills and capping high divides on their flanks. The significance of this evidence as to the source of the volcanic material and the extent of eruptive vulcanism will be discussed in a later chapter.

The presence in the White Ash layer of abundant vertical pipe-like concretions with tapering terminations, and small central hollow tubes averaging from $\frac{1}{16}$ to $\frac{1}{8}$ inch in diameter, offers an interesting problem. The central tubes are lined with minute crystals of zeolites often of radiate structure. The varieties of zeolites have not been determined, but mordenite (index of refraction 1.465) seems to be one of them. The latter also occurs in needle-like crystalline development lining small cavities in the body of the ash. These concretions and zeolite-filled cavities are found only in the ash, most markedly in the White Ash layer at the base of the Rosebud, and also in

the ash beds immediately above and below. The average length of these concretions is from four to six inches. The average diameter is one to two inches. Their shape resembles that of a coprolite (Pl. 8, Fig. 2). These concretions can be well observed in the Stony Pass section of Sheep Mountain.

Walker [61] has described a structure in the Basalt flows of Nova Scotia which seems to present a fairly close parallel to these concretions. He states: "In certain parts of this section (south side of the Bay of Fundy) the writers observed a peculiar structure in the basalt which consists of a development of vertical pipes or cores. These are sometimes coarsely amygdaloidal. At other times, where the basalt is fairly dense, cylindrical cores are developed which appear to be of the same rock type as the general mass in which they occur. At one locality (1½ miles east of Morden) the reddish amygdaloid in the low cliffs along the shore is penetrated by vertical cylindrical structures from one to four and a half inches in diameter and at times two yards in length. The material of these cylinders is characterized by the presence of white amygdules of zeolites from ⅛ to ½ inch in diameter which are more abundant near the margin of the cylinders than at the centre, while the main mass of the basalt is not marked by any prominent amygdaloidal structure. On a flat surface of basalt below high tide . . . the writers observed within a radius of four feet 25 tubes, 18 of them from 1¼ to 1¾ inches in diameter." He states that the mineral mordenite first discovered at Morden, N. S., occurred in the cylindrical concretions along with the other zeolites.

The explanation which he believes most suitable is as follows: "It is simpler to regard the tubes as caused by ascending currents of gases, probably water vapor rising from the wet floor beneath the igneous mass. This gas would make its way into the magma through cracks in the chilled floor of basalt and operate under considerable pressure in a continuous stream during the period of consolidation. The ascending gases, owing to the lessened pressure and consequent expansion, should have a cooling effect on the walls of the tube, and so cause this part of the mass to consolidate first and be finer in grain. . . . In some cross-sections . . . there is a well-marked concentric

[61] "Contribs. to Canadian Mineralogy," 1922, Univ. of Toronto Studies, Geol. Series, No. 14, pp. 5–12.

arrangement surrounding the pipes, that nearest the pipes being finer in grain and less amydaloidal than elsewhere. The open tubes like those found at Ste. Croix cove might be due to gas pressure at the end driving out the last available magma and leaving openings for the deposition of quartz and zeolites." [61a]

The conditions of formation of the concretions in the White River formation in the Big Badlands must differ notably from those described above, as the volcanic material was there both solid and cool at the time of its deposition. The concretions in the White Ash layer do not resemble those from the basalt in appearance, but the similarity in the shape and size of the tubes and their spacing and the presence of zeolites, notably mordenite, in both indicates that their mode of formation may have been at least similar. Griggs [62] has shown that solutions derived from volcanic ash may be strongly impregnated with acids even after the ash has been carried over a thousand miles in the air, so that brass fittings on automobiles in the Puget Sound region were tarnished by acid from the ash of the Katmai eruption. Therefore the cylindrical pipes filled with these tubular concretions may have been formed by gas explosions or the upward escape of imprisoned water, CO_2, or even air, and the zeolites produced by crystallization of material derived from the ash. In one or two cases one concretion was observed to have slipped over another, with the production of a slicken-sided surface, which Lawler [63] attributes to vertical stress.

The Rosebud Beds Above the White Ash Layer.—In the sections at Sheep Mountain and Cedar Pass, Interior, the beds above the White Ash layer closely resemble those immediately below it. They are gray or pinkish in color and consist largely of volcanic glass and pumice. The exposures of the Rosebud are in steeper slopes than those of the White Ash layer, as they are not so thoroughly consolidated into rock. At the top of the section at Sheep Mountain, the Rosebud beds are a little more sandy in character than immediately above the White Ash layer, and the same is noticeable at Interior. In the section northeast of Imlay, on the divide between Sage Creek and

[61a] Ibid.

[62] "The Valley of Ten Thousand Smokes," Nat. Geog. Soc., 1922, pp 25–29.

[63] *Am. Jour. Sci.*, Vol. V., Feb., 1923, p. 172.

White River drainage (Fig. 6, *D*), a coarse stream channel sandstone with numerous large rounded pebbles of ash, evidently derived by the stream from the erosion of its banks, occurs about ten feet above the White Ash layer, capping the section. At Interior, east of Cedar Pass, a heavy sandstone 140 feet above the White Ash layer caps the section. This is bed *F* of Ward's section of the Protoceras beds.[64] The similarity of these Rosebud ash beds to those of Leptauchenia age and the presence of channels in them resembling the Protoceras channels indicates that, though these beds may be classed as Miocene on faunal grounds, the depositional conditions were not greatly changed. Matthew[65] gives a thickness for the Rosebud on Porcupine Creek of 500 feet and states that, although "the beds at the bottom approximate the rather hard clays of the Upper Leptauchenia beds, they become progressively softer and sandier toward the top and are capped at Porcupine Butte by a layer of hard quartzitic sandstone." The Lower Rosebud beds are the highest Tertiary formations exposed in the area of the Big Badlands. The evidence on the post-Miocene history of the area is treated in a later chapter.

III. Physiography and Climate of White River Time.

The climate existing in the Great Plains region in Oligocene time is one of the most important of the environmental factors conditioning the life of the time. The best absolute measures of climate are supplied by fossil plants, as these, according to Knowlton, are the most sensitive indicators of changes of temperature or moisture. Unfortunately there is very little floral evidence to be derived from the White River beds (at least in their South Dakota exposure), but what little is to be found may be very instructive. In three seasons in the field only one petrified tree trunk (*Celtis*) has been found, in the basal Titanotherium beds in the west branch of Corral Draw, above referred to. However, through the clays of the Oreodon beds, wherever a careful search is made, a fair collection of fossilized seeds of *Celtis* (hackberry) may be found. They must occur through the clays in millions and Dr. Chaney[66] believes that their abundance may

[64] Op. cit., p. 30.

[65] *Bull. Am. Mus. Nat. Hist.*, Vol. 32, p. 169.

[66] Personal communication.

"have an important bearing on the physical conditions under which the sediments were laid down. A living member of the genus, *Celtis reticulata*, which grows in the southwest, is common along dry or intermittent water courses in the Colorado desert. In one of my Great Basin floras, probably of Oligocene age, I am finding leaves of *Celtis* rather abundant. These are more closely related to *Celtis reticulata* than to any other living form. There seems to be little doubt as to the habitat significance of certain members of this genus." An examination of the data on plant associations in Harshberger's "Phytogeographic Survey of North America" [67] shows that, although *Celtis* has a very wide range among deciduous forest associations, it is capable of persisting under conditions of poor sandy or gravel soil, or climatic extremes where many of its associates in the deciduous forest can not hold their own. Thus it is among the forests being destroyed by advancing sand dunes on the New Jersey coast; it grows on the sand dunes on the Barrier Islands of the Gulf Coast of Texas; in the sandhill country of western Nebraska it is common in narrow belts bordering the stream courses; it is characteristic of the foothill belt of the eastern Rocky Mountains; it is one of the trees derived from the east, extending farthest west into the Great Plains of the northern states, and is one of three eastern trees extending farthest into the Texas Plateau country. It grows along streams and flood plains in the Rio Grande and Chihuahua desert country, and in valleys along the eastern flank of the Sierra Madre. From the persistence of *Celtis* in the warm desert regions of Chihuahua and its endurance of the cold winters of the northern great plains it is evident that it offers no key to the temperature conditions of White River time. The fact that *Celtis* grows at present in many regions of slight rainfall shows that conditions of semi-aridity may have existed in White River time in the Great Plains region, where *Celtis* seems to have been one of the most important elements of the flora. *Celtis* probably grew along the courses of the streams of the Great Plains in Oligocene time, much as cottonwoods follow the modern badland draws.

The evidences of climatic conditions from the sediment itself may now be considered. While the suggestion of a semi-arid climate has

[67] J. W. Harshberger, "Phytogeographic Survey of North America," N. Y., G. E. Stechert & Co., 1911.

been brought forward, it is not to be thought that the climate was uniform throughout the duration of White River time. There were times when extensive shallow lakes characterized the surface of the plain, supporting a rich invertebrate fauna. There were times of greater aridity when ground water was drawn to the surface and deposited its dissolved calcareous material there as a cement for the silts of the surface, and there were evidently times of still greater aridity when gypsum was deposited, as described by Ward[68] and Fraas.[69] Furthermore, in the beautifully exhibited color banding of the White River clays and silts there are evidences of minor rhythmical fluctuations in climate.

As the question of the part played by climate and climatic changes in the deposition of the White River sediments is intimately tied up with the physiographic conditions of the region at the time of deposition, it will be well to review here the views on the physiographic conditions during White River time expressed by several geologists who have studied the area. The following discussion shows the gradual change of geological opinion as to the origin of the Tertiaries of the Great Plains from the volcanoes and convulsions of Culbertson and the lakes of Dutton and Hayden to the prairie loess of Matthew, the subaërial delta of Johnson, the lakes and flood plains of Fraas, the rivers and flood plains of Hatcher, and the rivers and shallow ephemeral lakes of Ward.

Thaddeus Culbertson in 1850 visited the White River Badlands and made a small collection of fossils for the Smithsonian Institution in the valley of Bear Creek, about three miles northeast of the present town of Scenic. He was the first to describe these badlands, and though not a geologist, was greatly interested in the problem of how they were formed. In his diary[70] he writes: "In thinking of how these lands were formed, it occurred to me very forcibly that it was by some convulsion of nature by which the ground sunk—the hills were not elevated, but were left so by depression of the surrounding land. . . . A few miles from the creek we passed over some hills that

[68] Op. cit., p. 22.

[69] *Science*, N. S., Vol. XIV., No. 345, Aug. 9, 1901, pp. 210–212.

[70] 5th Ann. Rept. of Board of Regents of Smithsonian Institution, 1851, pp. 92–93.

gave evidence of having experienced the most violent convulsions; these appeared to have been upheaved and to have experienced the action of fire; one place suggested the idea of a volcanic crater; it was a slight hollow and contained a number of small rocks different from any around it."

Dutton [71] wrote: "I know of no more impressive and surprising fact in western geology than the well-attested observation that most of the High Plateau area has been covered by fresh-water lakes. . . . The marvel is not in the fact that here and there we find the vestiges of a great lake, but that we find these vestiges everywhere. The whole region, with the exception of the mountain platforms and pre-existing mainlands, has passed through this lacustrine stage. . . . We know that the Miocene climate of the west was moist and subtropical. This is indicated by the great extent of fresh-water lakes in some portions of the west, their abundant vegetable remains, and the exuberance of land life."

Hayden (1867)[72] wrote: "I would infer that this great fresh-water lake (White River) must have spread over 150,000 sq. miles. . . . With the commencement of the Tertiary was ushered in the dawn of the great lake period of the west. The evidence seems to point to the conclusion that from the dawn of the Tertiary period, even up to the commencement of the present, there was a continuous series of fresh-water lakes all over the continent west of the Mississippi River. . . . Every year, as the limits of my explorations are extended in any direction, I find evidences of what appear to be separate lake basins, covering greater or less areas."

Matthew [73] was one of the first to abandon the lacustrine theory for the origin of the White River sediments. He believes that the larger part of the finer clays of the White River of Colorado are "chiefly eolian deposits, similar in origin to the prairie loess . . . picked by the wind from exposed surfaces and deposited on the sodded, or partially sodded, prairie surface." He believes that most of the sandstones, especially those of lenticular character, represent river deposits. He also expresses the opinion that the fauna lived in

[71] U. S. G. S., Monograph II., p. 216.

[72] Geol. Surv. Terr., 1st Ann. Rept., p. 58; and 2d Ann. Rept. pp. 114–115.

[73] *Am. Naturalist*, Vol. 33, pp. 403–408, May, 1899.

an open grassy region, and is paralleled by the fauna of the dry high plateaus of Africa of today.

Johnson[74] (1900) rejects the lacustrine theory and describes the Tertiary of the Great Plains as a debris apron or subaërial delta deposit made by distributary streams after emerging from the front of the Rocky Mountains in narrow canyons overloaded with sediment, on a gently inclined plane away from the mountains. This debris apron accumulated on a graded slope or gradation plane which had been eroded on the surface of the older Cretaceous deposits. He states (p. 622): "A series of streams from a mountain range, which in humid lands would persist upon independent courses and excavate valleys, may in arid lands unite by broad branching and interlacing flow and build up the original surface to a smooth and far extended apron of debris. This debris apron, having the profile of a graded stream bed along all lines in the direction of its slope, will be a gradation plane, sensitive as a whole to any disturbance by outside influences, of the equilibrium between its opposite grading forces, just as the single profile is sensitive."

Professor Fraas,[75] of Stuttgart, after visiting the White River Badlands in 1900, expressed the following opinion of the physiographic conditions of White River time: "At the beginning of the Oligocene a broad, slowly moving stream spread out toward the east and formed a broad, widespread and uniform delta landscape (Titanotherium beds). This even, swampy land was dry during the dry seasons, but was flooded in every high-water period; besides the water the wind frequently took part in the transport of dust and materials. The concretions are structures of the percolating waters (Lower Oreodon beds, numerous land mammals). Now followed a long period in which this region was flooded by a shallow rather than deep lake. The inflow of water did not exceed the evaporation and so through the varying concentration there was a precipitation of the dissolved materials which gave rise to the banded layers. In the same manner the gypsum and barite in these layers is explained. Stronger currents poured in sand, which accumulated in low elevations (Middle Oreodon beds). At last there came a widespread eolian condition in the

[74] U. S. G. S., 21st Ann. Rept., Vol. 4, 1900, pp. 612-656.

[75] Op. cit.

form of loess, which spread out upon the gradually retreating or evaporated levels of the Lake (Leptauchenia beds)."

Hatcher,[76] who probably had a better acquaintance with the White River formations than any other geologist, through his many seasons of collecting in them, rejected the lacustrine theory and believed that "the sandstones, conglomerates, and a portion of the clays were deposited in river channels, while the limestone lenses, so rich in the remains of aquatic plants and mollusks, originated in shallow ponds and lakes scattered over the higher table-lands and the broad flood plains of the rivers, where for the most part the finer clays were deposited by occasional inundations and through the agency of winds." He compares this with the confluent flood plains of the Upper Paraguay, Amazon, and Orinoco rivers, an area "equal to or greater than that occupied by the Oligocene and Miocene deposits of our western plains, with all the physical conditions necessary for the deposition and present distribution of the sandstones, clays and conglomerates, together with the preservation of remains of the faunas characteristic of each."

Recently Ward[77] has revived the lacustrine theory in a modified form. He accepts the fluviatile origin of the stream channels, but says: "The fact that the bulk of the Badland sediments are fine textured and that there is no apparent coarsening of the texture except quite near the Black Hills indicates that weathering at the source must have been extensive and deep. At the same time the soils developed by weathering were not thoroughly leached nor completely oxidized." To explain the alternations of shales and sandstones (other than channels), he believes that "intermittent and recurrent uplift" is a more satisfactory explanation than climatic changes. In regard to flood-plain deposit he says: "The clays, of course, required water for their deposition. While some of the smaller thin beds may have been deposited as flood deposits on a flood plain, most of them must have been laid down in lake waters. The chief reason for thinking so is the marked continuity of the beds, their uniform character, and considerable thickness. . . . Clay deposits on present-day flood plains, such as the broad Missouri . . . are commonly thin and do not

[76] Proc. Amer. Phil. Soc., Vol. XLI., April, 1902, pp. 113–131.

[77] Op. cit., pp. 36–40.

keep their continuity for more than a few hundred feet, and very rarely can a bed be traced a quarter of a mile. The shale beds of the Tertiary are continuous commonly for a quarter to three quarters of a mile and a few are a mile or more in extent, while all of the Titanotherium and at least one shale bed of the Oreodon are continuous over the whole area." He believes that the climate " must have been humid and temperate or cool and the relief moderate."

From the above quotations it will be clear that the interpretation of the climate and the climatic changes of White River time depends fundamentally on which of the many diverse views regarding the conditions of sedimentation is adopted. Also the climatic significance of alternate bands of greenish and pink or red silts and clays should be understood, and here again there is a diversity of opinion. Tomlinson [78] believes that the ferruginous material of red beds was transported and deposited almost, if not quite, wholly as a mechanical sediment, both independently and as a coating upon grains of other materials, and that in many cases the green shales or sandstones alternating with the red are caused by the reduction of the ferric iron by organic material in the original sediment. Barrell has suggested that the green or gray strata in red beds are coarser than the red and their deoxidation may be due to the fact that [79] " more abundant ground waters in the sands may have kept out the air and permitted the organic matter to accomplish its effects." In another place [80] he states that " where lightness in color is due to chemical causes it is to be noted that the first result of the action of fermenting organic matter upon ferruginous clays is a change of color from rusty to bluish or greenish by the reduction of ferric to ferroso-ferric hydrate. Afterward, if the action be continued, the solution of ferrous carbonate may be formed, and the greenish or bluish color may disappear. The importance of this reaction lies in the fact that the blue or green, wherever it occurs, indicates a lack of aëration usually by the stagnation of water in consequence of imperfect drainage. . . . Where such colors are rather abundant, however, over broad areas of non-marine formations, a mean rather than an extreme climate is indicated."

[78] *Jour. of Geol.*, Vol. 24, 1916, pp. 153–179, 238–253.
[79] *Amer. Jour. Sci.*, 4th Ser., XXXVI. (1913), p. 469.
[80] *Jour. of Geol.*, Vol. 16, 1908, pp. 293–4.

In the White River formation the green silts and sands generally occur in lens-shaped bodies. The stream channels are generally greenish colored, and there are finer-grained outliers of the channels frequently showing abundant flakes of muscovite mica. Farther away from the channels are beds of fine green silt hardly distinguishable from the reddish clay in composition or texture. The green beds are rare away from channels through most of the series, but in the Middle Oreodon beds there is a very widespread development of greenish sands and silts (Division 4). Plate I., Fig. 1, shows this zone clearly as developed in Battle Creek Draw. This widespread green zone may represent a period of greater rainfall when a broad river flowed over the area where the heavier sandstones were developed and frequently flooded the plain away from its valley, perhaps leaving stagnant pools here and there on the surface of the plain between times of flooding. This would seem to be the condition most likely to prevent the iron in the clays and sands from being oxidized to a ferric condition. The green bands may be considered then to represent deposits made under a cover of water, as stream channels, or on a soil surface saturated with water, such as might occur immediately adjacent to stream channels. It may be noted here that the Titanotherium clays, though gray and spongy on the surface, are moist a foot or so below the surface and are uniformly colored pale green.

In Ward's recent paper, above cited, the opinion is expressed that flood-plain deposits would not be as extensive and uniform as those found in the White River. The uniformity and extent of deposition of certain layers is surprising, but the lithology, fossil content, and structures of the deposits seem to demand deposition on a surface generally exposed to the air and only occasionally flooded. Davis [81] describes a flood plain in Central Turkestan that is so similar in character to that postulated for the White River area that a little of his description may be profitably quoted. "The surface was absolutely plain to the eye except for the dunes and the dunes departed from the plain only as wind waves at sea depart from a calm surface. Although apparently level, the plain has slope enough to give the Tejen, the Murg-ab and the Amu rapid currents, in which these rivers carry forward a great amount of mountain waste. . . . The rivers have

[81] "Explorations in Turkestan," Carnegie Inst. Pub. 26, 1905, p. 54.

great variations in volume. . . . We were fortunate enough to see the Tejen and Murg-ab in flood. The former overflowed its channel and spread in a thin sheet for miles over the plain. The latter would have spread but for the restraint of dikes at Merv. Some of its waters had escaped farther upstream, and came to the railroad, wandering across the plain among the dunes, a curious combination of too much and too little water supply. The most notable feature of the region was the absence of valleys. The rivers had channels in which their waters are usually restrained, but there were no valleys in which the river floods were limited. The plains were open to overflow as far as flood supply held out." The difference between the flood plains of the western region of today such as those of the Missouri River, cited by Ward, and those which must have been the seat of deposition of the White River beds is that these modern rivers are entrenched below the level of the high plains, and it is therefore impossible for their flood waters to extend farther from the stream than the sides of the valleys. The present cycle in the plains region is primarily one of degradation and is characterized by local and temporary flood plains in contrast to the broad uniform plains of aggradation of middle Tertiary time.

As the writer's interpretation of the significance of red and green colors in the sediments and of the physiographic conditions of the area during deposition have been outlined, a brief sketch of the climatic and physiographic history of White River time may now be presented.

After the Cretaceous period a long time of erosion with peneplanation ensued under mild or humid conditions, during which a residual soil mantle rich in ferric oxide was accumulated. This soil mantle reached a depth of 30 or 40 feet, the thickness of the "Interior" formation. This is the initial graded slope of erosion upon which the plain of aggradation formed by the mantle of Oligocene and Miocene sediments is based.

At the beginning of White River time greater aridity removing the vegetation or, more likely, primary movement of uplift in the Black Hills to the west, caused the entrenchment of streams in this old soil surface, with the result that, in places, the whole of the

residual soil was removed and dissection continued for a short distance into the Pierre shale. The rejuvenated streams engaged in this dissection carried with them pebbles from the Black Hills which from their freshness indicate quite rapid transportation. Gradually the valleys were widened and soon a more gentle relief caused the streams to wander somewhat upon the surface of the valley floor depositing sands in their channels and steeply cross-bedded silts as lateral delta terraces on the sides of the valleys. Thus, with perhaps a slightly more arid climate the streams gradually aggraded the valleys which they had cut in the old residual soil surface until once again a plain existed. The iron from the old soil was contributed sufficiently to the silts of the valley to color these beds strongly, as mentioned above. When the streams of Titanotherium age had aggraded to the level of the old plain they were no longer bound in by valley walls and were free to wander at will across the plain. Thus when torrential downpours in the Black Hills brought down sheets of water they were not limited by the sides of the valleys, but spread far and wide over the plain, each flood leaving an additional thin sheet of silt. A mild climate with sufficient rainfall existed and animal and plant life was probably abundant. Local lakes existed over the plain where slight depressions ponded the waters from the floods and held the local rainfall and in them flourished a rich algal growth with associated fresh-water invertebrates which formed the many local lenses of limestone now found through the Titanotherium beds.

After a long period of time erosion again predominated over sedimentation, with conditions favorable for carrying the silts from the hills to a greater distance before their deposition. Also with a more humid climate the Black Hills would be more completely covered with vegetation and streams emerging from them would not be so overcharged with sediment as under the previous more arid conditions. We do not know the length of time represented by this erosion interval, but it was probably shorter than that represented by the deposition of the Titanotherium beds. At the close of this period of erosion all the depressions on the surface seem to have been the sites of local ponds in which fish, cyprids, fresh-water gastropods, and algæ flourished. Some of these may not have been actual ponds, but rather damp marshy meadows.

With the close of this algal pond stage climatic conditions swept to an arid extreme which may have caused the disappearance of a large part of the cover of vegetation. In the opinion of the writer this climatic change may also have been responsible for the sudden disappearance of *Titanotherium*. In the sediments it is represented by the marked increase in the amount of calcareous cement. Again shallow streams meandered across the plain and spread broad sheets of silt many miles away from their channels. A large and varied fauna roamed over the grassy plains, and an aquatic fauna typified by the massive rhinoceros *Metamynodon* frequented the river channels. Several times after a period of flood the surface of the plain remained dry, perhaps for many years, and the surface silts were cemented to a hard caliche or nodular level by the deposition of the soluble content of the ground water when it was evaporated. As the ground water was drawn to the surface by capillarity a small film of water would remain around each fragment of sand or silt, and when this film was evaporated a thin coat of cement would be deposited on the surface of the grain. Gradually these films grew in thickness until they joined adjacent grains and eventually formed the whole into a solid mass. This condition was repeated several times during the deposition of the Red Layer. The fact that the caliche nodules are most strongly developed in the vicinity of stream channels, as mentioned above in connection with the Lower Red layer (Division 1 of the Oreodon beds), is probably due to the fact that the soil was more nearly or more frequently saturated with water here and consequently contained a larger amount of carbonates in solution than did the clays away from the stream channels.

After a long period of caliche development, there was a change to a somewhat more humid climate and stream channels became more numerous, and again local ponds with fresh-water faunas were developed over the surface of the plain. This zone is characterized by more frequent alternations of pink and green sediments. It was still, however, apparently more arid than Titanotherium time, as the sediments contain a larger amount of calcareous cement than did those of the latter. This period was closed by a short recurrence of caliche-forming conditions representing only one period of semi-aridity, as

there is only a single level of nodules (the Upper Nodular layer). The Upper Nodular layer was followed by even more humid conditions than those preceding it, as the beds of division (4) are predominantly green and coarser in grain. As stated above, this green coloring probably represents widespread flood-plain conditions and probably a wider main channel than that of earlier White River time. The flood plain of the upper Mississippi near Lacrosse, Wis., with extensive bottomlands on either side of the river covered with water the greater part of the time is perhaps a similar case, except that the Mississippi is deeply entrenched below the level of the plain, while the Oreodon beds stream flowed in a shallow channel on the surface of the plain. This condition persisted for a period about equivalent to that between the lower and upper caliche levels and was followed by a recurrence of conditions of greater aridity, when red clays far predominate over green and channels are few and small. No caliche beds were observed here, partly because almost no channels are seen at this level.

Gradually another factor was impressing itself on these previous rhythms of climate and deposition, namely, increasing contributions of volcanic dust from outside the drainage areas of the White River streams in this district. As the wind-transported ash was probably distributed quite uniformly over the whole area, the Black Hills as well as the badlands, and as it would form a light unconsolidated deposit wherever it fell, the streams would naturally easily remove the ash from the surface, and from this time on it would be an important element in the stream-transported sediments as well. Furthermore, the erosion and transportation of the normal clastic sediment from the Black Hills might be to some extent reduced if the carrying capacity of the streams was filled by the easily eroded ash.

At the beginning of Leptauchenia-Protoceras time there seems to have been a slight return to more humid conditions, as stream channels became more abundant and extensive, but there soon ensued a period of caliche formation similar in character to that of the Lower Nodular layer and resulting, as did the latter, in a series of levels of nodules probably each representing old land surfaces. Also, as in the former case, the animals of the plain are abundantly preserved in

the caliche levels. The only difference between the Oreodon and Leptauchenia caliche nodules is that in the latter volcanic ash generally forms 50 per cent. or more of the clastic material of the sediments, and clay pellets are absent.

The massive distinctly laminated beds of the Upper Leptauchenia series directly below the White Ash layer rather resemble in their finer lamination the massive green sandstones of the Middle Oreodon beds, and it may be that they represent a recurrence of extensive flood-plain conditions with broad rivers. In these beds, as in the caliche layers underlying them, the primary character of the physiography and normal sedimentation is masked by the fact that from 50 to 75 per cent. of the clastic sediment is volcanic ash. The greater degree of cementation of these beds may be attributable with greater probability to solutions from the ash rather than to normal processes of evaporation, such as seem to control the cementation in the Titanotherium and Oreodon beds.

Following the massive laminated beds above referred to occurred the great showers of ash which completely dominated the sediments giving layers of pure ash over most of western South Dakota and Nebraska and eastern Wyoming. Here the ash completely dominates the sedimentary structure so that no suggestions as to the climate may be offered.

Continuing into the Rosebud there appears to be a recurrence of conditions similar to those before the deposition of the White Ash layer, and, according to Dr. Matthew, through the Rosebud there is a rather progressive change to more sandy sediments and an apparent increase in the importance of æolian action. The deposits of the Rosebud are too thin and too isolated in the Big Badlands north of White River to study the physiographic relations, but it can be stated that there still appear to have been river channels carrying coarse sediments from the Black Hills, and as far as can be seen in the Big Badlands area the lower part of the Rosebud sedimentation was as completely dominated by volcanic ash as was the sedimentation during Leptauchenia time.

The upper Miocene and Pliocene history of the region is a blank as far as deposition is concerned, for whatever sediment may have

been laid down during that time was later removed by erosion in the peneplanation of the surface, resulting in the formation of the high plain of which Hart Table, Sheep Mountain Table, and other high table lands in the district are remnants. The evidences of late Pliocene and Pleistocene physiographic and climatic history will be discussed in a later section.

Although the foregoing analysis of the climatic history is only tentative and may be changed materially by further investigation, it seems to show that there is, in the White River sedimentation, evidence of a very remarkable series of minor climatic cyclical or rhythmic changes, much like those which Huntington [92] has discovered in the Pleistocene history of the enclosed basins of Central Asia and in the climates of southern and western Europe of the past 2,000 years as narrated in classical and mediæval history. In the opinion of the writer, the fact that changes in character of the sediment such as caliche formation, alternations of green and pink silts, etc., are found to be uniform over such wide areas indicates, as Johnson [93] has suggested, that "this debris apron, having the profile of a graded stream bed along all lines in the direction of its slope . . . will be sensitive as a whole to any disturbance by outside influences." If this is the case, and if the climatic interpretation of continental sediments such as these can be standardized, the climatic history of the area may be deciphered with a preciseness heretofore unknown in the study of ancient climates.

Evidences of Regional Uplift During White River Time.—As the effect of strong uplift of the Black Hills might affect the sediments deposited on the plains to the east of the Hills in the same manner as would certain climatic changes, it is difficult to differentiate these two causes. If the Black Hills were suddenly raised much higher than they had been above the surrounding plains, the effect on the climate would be the production of greater rainfall in the Hills themselves, and of greater aridity on the plains to the east. In the opinion of the writer, marked uplift of the region of the Black Hills may have been

[92] "Explorations in Turkestan," Carnegie Inst. Pub. 26, 1905, pp. 182–216, 227–232, 253–275, 302–315. Also the "Pulse of Asia," "Palestine and its Transformation," and "World Power and Evolution."

[93] Op. cit., p. 622.

important in initiating the deposition of the sands and silts of Titanotherium age on the eroded peneplain of the Interior beds.

In the Oreodon and Leptauchenia beds certain subdivisions defined above have been recognized almost everywhere through the area of the Big Badlands. As complete sections from the base of the Oreodon beds to the top of the Leptauchenia beds are available both in the Big Badlands (Corral Draw district) and at Interior, about 50 miles to the east—*i.e.*, farther away from the Black Hills, the source of the clastic sediment of the White River—an interesting comparison may be made of changes in thickness observed in the subdivisions of the Oreodon and Leptauchenia beds. The accompanying diagram, Fig. 9, shows the generalized section of the Oreodon-Leptauchenia beds of the Big Badlands contrasted with that of the Cedar Pass section northeast of Interior. As the three subdivisions of the Leptauchenia beds recognized in the Big Badlands have not been distinguished at Interior, their respective changes in thickness can not be shown. It will be observed that the Lower Red layer (1), the color-banded silts and clays overlying this layer (2), and the upper reddish clays of the Oreodon beds remains remarkably constant, showing a variation of three feet or less in these sections separated by 50 miles. In contrast to these the Middle Oreodon sandstones or sandy silt beds (4) change from 50 feet in the Corral Draw sections to 24 feet in thickness, maintaining the same character at both places, and the Leptauchenia beds change from 192 feet to 72 feet in the same distance. The White Ash layer shows minor variations in thickness from point to point, but as it is not considered a stream-transported sediment, these would have nothing to do with uplift of the Black Hills or with climatic change. The rapid thinning of the Middle Oreodon sandstone away from the source seems to indicate that the streams emerging from the Black Hills at this time were loaded with coarser sediment than they were, for instance, at the time of the deposition of the Lower Red layer. With an increasing gradient or graded slope away from the hills this coarser sand would be deposited nearer the Hills than would the fine silt of the Lower Red layer. Greater erosion in the Black Hills due to greater precipitation or sudden uplift, or a combination of these factors, may be

the cause of coarser sediment in the Middle Oreodon beds over such wide areas. The sharp delimitation of this sandstone series at the top and base by red clays and caliche beds suggests that the immediate cause of the change in thickness and character of the sediment here is climatically controlled, though regional uplift may have been taking

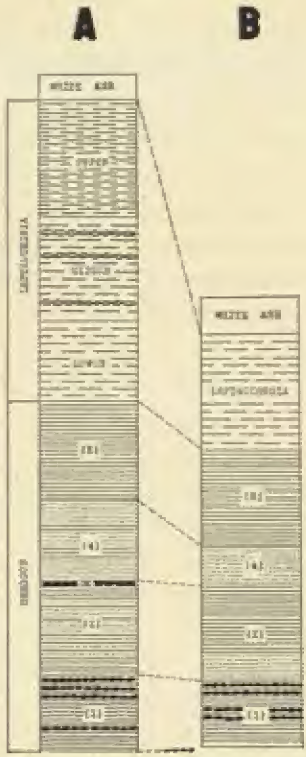


FIG. 9. Parallel sections of the Oreodon and Leptauchenia beds and the White Ash layer in the Big Badlands (*A*), and in the Wall of the Badlands, northeast of Interior (*B*), to show the persistence in thickness of some members of the series and the marked thinning of the Leptauchenia beds and Division 4 of the Oreodon beds. Section *A* is generalized from the Cooney Table Section, Corral Draw, and the Cedar Butte Section, Cottonwood Creek, and Section *B* is detailed. Vertical scale 120′ = 1″.

place at the same time. The change in thickness of the Leptauchenia beds resulting in a thinning away from the Black Hills may have been caused by the streams near the Black Hills carrying a heavier load of

sediment than they would normally, because of the great mass of easily removed volcanic ash on the surface everywhere. Here, again, the streams would be likely to deposit much of their load near the Black Hills. Thus it seems possible to present a reasonable explanation for each case where the deposition is observed to depart notably from its usual uniformity without demanding an "intermittent and recurrent uplift" of the Black Hills, which Ward[85] believes to be the best explanation of the alternation of sand and clay beds in the White River series. In the opinion of the writer, broad and long-continued uplift of the Black Hills took place during the Tertiary and in a general way may have exerted an influence upon the cycles of erosion and deposition during this time, but the sudden changes in the character of the sediment and the short erosional breaks, such as that at the close of Titanotherium time, can best be interpreted as the result of climatic change.

IV. Volcanic Ash in the Oligocene Formations of the Cordilleran Region.

The presence of volcanic ash as an abundant or dominant constituent of the clastic sediments of the upper White River and Lower Rosebud has been referred to repeatedly. The wide geographical distribution of the White Ash layer has also been mentioned. The source of the volcanic material is a problem which is important in this connection.

It is well known that very extensive vulcanism accompanied the Tertiary orogeny of the Rocky Mountains, and therefore it is not surprising that volcanic ash should be an important constituent of the sediments. Sinclair and Granger[86] describe a level of white tuffs of rhyolitic composition in the Wind River formation along the Beaver Divide of the Wind River basin; a bed of tuff 25 to 75 feet thick in the Bridger in the same section. In the Oligocene (Titanotherium beds) which caps the section there is a dominance of volcanic material, and its structure shows that the source was near at hand. "Extensive volcanic eruptions broke out somewhere in the vicinity, and the first deposit laid down in these troughs was a fine-grained tuffa-

[85] Op. cit., p. 37.

[86] *Bull. Am. Mus. Nat. Hist.*, Vol. XXX., pp. 83–117.

ceous shale. . . . Vulcanism soon became very violent, ejecting great blocks of hornblende andesite, which, with ash, pumice, lapilli, and pebbles and cobbles of pre-Tertiary rocks, were swept down the valleys as mud-flows. The vents from which this material came have not been located. They continued in eruption during the whole of the Lower Oligocene, as here represented, showering the region with dust." Above the agglomerate flow occurs a bed of coarse gravel, and resting unconformably on this are found 528 feet or more of fine buff-colored ash and dust. This ash is generally consolidated by calcareous cement, and becomes increasingly calcareous toward the top of the section. Merriam [87] has shown that most of the clastic sediment of the John Day is ash or volcanic agglomerates, and Darton [88] has described numerous ash layers through the Brulé clays and Arikaree sandstones of the Great Plains, while beds of volcanic ash of Pleistocene age are known as far east as Omaha, Nebraska. Matthew [89] believes that volcanic ash is "almost the principal source of terrestrial sediments in the Tertiary formations of the west."

To return to a consideration of the source of the volcanic material of the Big Badlands, the first to be considered is the Black Hills. The majority of the clastic material of the White River in this area is derived from the Black Hills, and as it is known that laccolithic intrusion was occurring on a large scale in the northern Hills during the Tertiary, eruptive vulcanism is, also, possible. Darton [90] has described "a sheet of obsidian and associated agglomerates which doubtless are the products of surface extrusion . . . 6 miles south by east of Deadwood in the midst of a large area of pre-Cambrian schists. . . . The obsidian is a sheet about 15 feet thick and of small extent. Its smooth lower surface lies on a one-foot layer of impure volcanic ash and is underlain by a thick mass of agglomerates or flow breccia of apparent rhyolitic fragments. This breccia is in masses surrounded by a deposit of finer grained ash which is nearly a square mile in extent. . . . The original vents are

[87] *Bull. Dept. Geol.*, Univ. California, Vol. 2.

[88] U. S. G. S., Prof. Paper 17, pp. 25–43, and plates and figures.

[89] "Problems of American Geology," pp. 389–392, 1915.

[90] *Science*, N. S., Vol. XXXVI., No. 931, "Volcanic Action in the Black Hills of South Dakota," 1912.

not preserved, but their stocks are represented by some of the dikes which occur at many places in the schists or overlying Paleozoic rocks." He suggests that this may show the Black Hills to be the source of part, if not all, of the ash of the Oligocene and Miocene deposits of South Dakota and Nebraska.

A more prolific source of volcanic material, though much more distant, is the volcanic basin of the Yellowstone National Park. Lindgren [91] says of this: "A great center of Miocene (Miocene and Oligocene) activity is in the Yellowstone Park region. Here the eruptions had already begun during the Eocene, but they continued in enormous volume during the Miocene and Pliocene. The early Miocene succession shows andesitic breccias followed by some rhyolite and basalt succeeded by heavy beds of andesitic breccia." In the Yellowstone Park at Specimen Ridge there are in one section from 12 to 15 successive forests buried by showers of volcanic ejecta, one above the other. This gives some measure of the duration of volcanic action in that region.

Griggs [92] has recently published some valuable data on the eruption of Mt. Katmai on the Alaskan peninsula. He presents a contour map of the thickness distribution of the ash from the data available, which gives us a good basis for the estimation of the size of an eruption, or eruptions, necessary to supply the ash for the upper White River and Lower Rosebud ash layers. The map shows a maximum deposition of 50 feet of ash within a mile or two of the volcano, thinning to 10 feet about 10 miles from the volcano, and 1 foot at a distance of 100 miles. At a distance of 300 miles (about that of the Big Badlands) from the Yellowstone Park volcanic basin the maximum thickness of ashfall is less than 0.1 foot. The influence of the prevailing westerly winds on the transportation of the ash is shown by the fact that the contour of one foot of ashfall approaches to within 15 miles of the volcano on its western side, while it extends 100 miles from the center to the east. The amount of material erupted is estimated at 4.75 cubic miles and it is believed to be the largest eruption recorded in human history.

When this is compared with the ashfall of the late Oligocene, the

[91] "Problems of American Geology," p. 270.

[92] "The Valley of Ten Thousand Smokes," *Nat. Geog. Soc.*, 1922, map opposite page 1.

tremendous volume of the eruptions which supplied the latter may be realized. Let us first consider the White Ash layer, which from its uniformity in thickness and character seems to represent practically a pure ashfall over a very wide area, apparently very little reworked by water or mixed with other clastic sediment. This has an average thickness in the Big Badland region of 14 to 20 feet. Darton reports 12 feet at Adelia, Nebraska, and 8 feet in the vicinity of Scott's Bluff, Nebraska, and 6 feet in the Goshen Hole region of eastern Wyoming. With this may be combined a thickness of 75 feet, mostly of volcanic ash, in a Tertiary outlier in the Bighorn Mountains. The upper part of the 528 feet of Oligocene ash in the Beaver divide section of the Wind River basin described by Sinclair and Granger [93] seems to be poorly dated by fossils, and part of it, for aught anyone knows to the contrary, may be of Leptauchenia beds age. A very conservative estimate based on the available data is that the ashfall had an average thickness of at least 10 feet over an area of about 60,000 square miles. This is equivalent to over 100 cubic miles of volcanic material, about 20 times the amount from the Katmai eruption. Consideration of the volcanic material mixed with clastic sediment in the other beds of the later White River and early Rosebud would probably raise the volume of the ash considerably.

Even supposing that this material came from the Black Hills, we find 8 or 10 feet of ash deposited at Scott's Bluff, Nebraska, 200 miles straight south of the possible volcanic vents of the Hills. The products of volcanic action in the Black Hills do not seem of sufficient magnitude to account for more than a limited amount of this volcanic material. Because of the known long duration of volcanic action in Yellowstone Park and the great deposits of Tertiary ash in Wyoming, we may say that, though there is no direct evidence that the White River ash came from this area, it seems to be the most likely adequate source of the volcanic material.

V. Chalcedony Veins and Sandstone Dikes. Cementation and Silicification of the Sediments.

Through the clays and sandstones of the White River formation occur numerous vertical or but slightly inclined fissures filled with

[93] Op. cit., p. 101.

clay, sand, or volcanic ash, or with thin veins of blue chalcedony. These are not uniformly distributed, some beds having these veins and dikes abundantly developed and others showing almost none, while at the same horizon they may be more abundantly developed in certain districts than in others. The chalcedony veins seem to be more localized than the sandstone or clay dikes.

Hatcher [94] and Lawler [95] have discussed the phenomena exhibited by these dikes and veins and agree in believing that the cracks were formed rather by a desiccation of the sediments of the White River after consolidation than by any general movement of the area, or by volcanic action.[96] As a rule there is no evidence of displacement along these cracks, but Lawler points out one example where a stratum of sandstone was offset about one foot on opposite sides of a massive chalcedony vein, with the surface of the latter slickensided. Similar slickensiding, without evidence of displacement on either side of a vein, is common, the chalcedony having duplicated the slickensiding of the clay wall, or perhaps taken a fibrous structure as the result of slight movement of the walls during the growth of the vein, which may have been due to a wedging apart or reopening of the veins by the deposition of the chalcedony.

It has been generally supposed that the filling of the dikes was from below, as many early investigators believed,[97] but the reverse was clearly demonstrated by the finding of a dike 15 inches in thickness in the Lower and Middle portions of the Oreodon beds filled with pure white ash unmistakably derived from the ash layer nearly 200 feet higher in the series (Pl. IX., Fig. 2). This means that the fissures were cracks open to the surface analogous on a very large scale to mud cracks, formed by the desiccation of a large amount of moist clay and silt, or by the squeezing out of part of the water from these clays by settling. Probably in some cases material was washed away from the side walls of the cracks, as well as washed in from the

[94] *Am. Naturalist*, 1893, Vol. 27, pp. 208–210.

[95] *Am. Jour. Sci.*, Vol. V., Feb., 1923, pp. 160–172.

[96] Diller, J. S., in *Bull. Geol. Soc. Amer.*, Vol. 1, p. 411.

[97] E. C. Case, "Mud and Sand Dikes of White River Oligocene," *Am. Geol.*, Vol. 15, 1895, and Robert Hay, "Sandstone Dikes in N.W. Nebraska," *Bull. Geol. Soc. Amer.*, Vol. 30, 1892, p. 50.

FIG. 1. Vertical clay ridge in middle Oreodon beds, Battle Creek Draw, cut obliquely by a sandstone dyke.

FIG. 2. Dike filled with white volcanic ash cutting Oreodon beds, 5 miles northeast of Imlay, S. D.

surface, indicated by the fact that many dikes show a vertical change in the character of their infilling. Usually the material forming the dikes is a fine silt or sand frequently with a large proportion of muscovite foils, but in a few places coarse stream-worn gravels were found. In one dike in Corral Draw in the Titanotherium beds pebbles rounded by running water and with a diameter of four or five inches were found. These must have been derived from an overlying stream channel of Metamynodon age of which there is now no visible trace. An attempt was made by Mr. Lawler to detect any definite directions or systems of directions which the dikes and veins followed, but there seems to be no marked parallelism between them. Some dikes can be followed in a straight line for a distance of from a quarter to half a mile and thus have quite a dominant influence upon the topography of the region. In the basin of Battle Creek Draw the dikes are abundant in the sandstones of the Middle Oreodon beds, and single dikes are there more continuous than at any other point where they were observed. In this basin there are also numerous faces of clay and sandstone which rise almost vertically from the valley floor. These ridges are frequently 40 or 50 feet high and only about 5 feet in thickness. The only explanation which the writer can offer for these comb ridges is that they owe their resistance to cementation by ground water along joint planes and systems. Plate IX., Fig. 1, shows one of these steep ridges of clay with practically vertical walls on both sides, which is cut diagonally by a conspicuous dike about 8 inches in thickness. The latter can be observed in a straight line for several hundred yards.

As Lawler points out, the genetic connection between dikes and chalcedony veins is clear in that sandstone dikes are often bordered on one or both sides by chalcedony veins. In one place a dike filled with rather coarse sandstone is bounded by greenish slickensided calcite.

An investigation of the lithology of the dike fillings leads to interesting conclusions. The dike fillings from the Upper Oreodon and Lower Leptauchenia beds generally show a fairly high ash content. The dikes are often quite thoroughly cemented and in one case the dike filling was such a tough rock that it was difficult to break it with

a hammer. It had the appearance of a quartzite or a fine-grained volcanic rock. The cementing material of the dikes is found to differ from that of the clays and sandstones of the Oreodon beds in that there is a very small amount of carbonates, averaging from one to eight per cent. The fillings seem to be mostly cemented by silica. In some samples this is in the form of blue chalcedony, while in one or two samples most of the matrix of the sand grains was found to be opaline silica, isotropic under crossed nicols (refractive index about 1.440), and showing a globular or spheroidal structure.

In the preparation of some fossil skulls the clay adjacent to the skulls was found to be cemented with silica into small irregular nodular masses. Graham has shown that the presence of phosphates may cause a silicic acid soil to set to a translucent jelly. Thus the phosphate from the fossil bones is probably responsible for the abundance of these small cherty concretions in their vicinity. The filling of pulp canals of fossil teeth and the marrow cavities of fossil bones with chalcedony, described in an earlier paper, may be caused in the same manner.

The cementation of the dikes with silica, the formation of chalcedony veins, the replacement of gypsum and barite concretions, the filling of marrow cavities and pulp canals of fossil bones and teeth with chalcedony, and finally the silicification of the fresh-water limestones, which are often almost completely replaced, points to an epoch when the ground water was charged with a high amount of dissolved silica.

The period of great ash deposition at the close of the White River and the beginning of the Rosebud seems the most likely time for this. As mentioned above, the ash when deposited was probably strongly charged with acids and water falling on it may have leached much of its alkali content, so that in circulating through the clays below these waters would be strongly alkaline. These waters would be capable of dissolving much silica from the clays and silts and then depositing it after a period of greater aridity. As the many fissures represented the lines of easiest movement for the ground water, they show the greatest effects of this silica deposition and the gypsum and algal limestone were also more easily replaced by the silica than the

rest of the series. It has been observed that in sections where chalcedony veins are abundant the limestone sheet at the base of the Oreodon beds is generally silicified, while in sections away from the chalcedony veins the limestones are largely unreplaced.

It is the opinion of the writer that the distribution of chalcedony veins, the silicification of limestone beds, and the development of caliche layers are all connected with the courses of the rivers of White River time, and this seems to be borne out by the following instances: In Corral Draw, where stream channels are abundantly developed with *Protoceras, Metamynodon,* and *Titanotherium* faunas, there is a strong development of caliche nodules in the Lower Oreodon beds and in the Leptauchenia beds adjacent to the Protoceras channels. The limestone bed at the base of the Oreodon beds is largely replaced by silica and chalcedony veins and sandstone dikes are abundant, especially in the Protoceras channels and the adjacent Leptauchenia beds. This is the only locality at which chalcedony veins were found in the Leptauchenia beds. On the contrary, in the Wall of the Badlands about six miles northeast of Imlay, in the Oreodon and Leptauchenia beds section, no stream channels are present in the Lower Oreodon beds; the Lower Red layer is represented by red clay without a development of caliche nodules; the limestone at the base, though present, is not silicified; there are no chalcedony veins and only one dike was observed, which was filled with white ash, shown in Plate IX., Fig. 2. The cause of this relationship may be the fact that only in the vicinity of the White River streams was the ground sufficiently saturated with water. In the wide interstream areas the sediment would be deposited by occasional flood waters, which would quickly drain back toward the river courses with the end of flood conditions. The silt would be finer in character and with desiccation the deposition of calcareous cement would be insufficient to produce a caliche layer, and with the consolidation of the sediments the contraction in volume would be less because there is less water to be squeezed out or evaporated, hence fissures of desiccation or settling would be smaller and less frequent than in the areas adjacent to river courses where there is more water in the ground to be squeezed out or evaporated. The formation of fissures probably took place at

various times during and since the White River, as the nature of the dike filling in many cases suggests what bed formed the surface at the time of fissure filling. The highest beds exposed in the area, the Lower Rosebud on Sheep Mountain and at the Cedar Pass section of the Wall of the Badlands near Interior, are cut by dikes filled with ash, sand, and clay, showing that fissure formation continued beyond the close of White River time. The chalcedony veins may have been formed during the period when wind-blown ash was the most important clastic constituent of the sediments—*i.e.*, in later White River and earlier Rosebud time. Therefore, though the ash was probably deposited uniformly over the surface of the plain, the silica charged waters from it were only able to move freely through the sediments where the fissures were most frequent, which was in the vicinity of the old river channels.

The streams of White River time seem to have confined their valleys to fairly limited belts, though their actual courses may have shifted two or three miles during the whole of the White River period. The abundant development of channels in the Corral-Quinn-Cottonwood Creek area through all the divisions of the White River and the absence of channels in all divisions in some sections, such as Lower Bear Creek and the Wall of the Badlands northeast of Imlay, seem to indicate this.

VI. Post-Oligocene History of the Region.

Although this subject lies outside the scope of the present paper, it may be briefly discussed. There are many facts observed in the field which indicate changes of climate and physiography since the deposition of the Rosebud. The stages of erosion, deposition, and climatic change here observed may to some extent be an index of stages throughout the Great Plains province. It is with the hope that this limited amount of evidence may be of value in tracing the full Pliocene-Pleistocene history of the Great Plains that this chapter is written.

Miocene Deposition.—As stated above, Miocene deposition in this area is initiated by the White Ash layer at the base of the Rosebud formation, which is preserved only in a few isolated high points

in the area of the Big Badlands, but is continuously exposed south of White River, and according to Matthew[99] reaches a thickness of 500 feet on Porcupine Creek. Middle and Upper Miocene beds are found 60 or 70 miles to the southward in western Nebraska, and may once have extended northward over the South Dakota Big Badlands, although now nowhere preserved there. The fact that isolated buttes in northern South Dakota (Cave Hills, Short Pine Hills, etc.)[100] are capped by Miocene deposits above the White River beds suggests that deposition continued in the belt to the east and northeast of the Black Hills well into the Miocene.

Formation of the High Plain.—A period of erosion and peneplanation followed the close of Miocene or Pliocene deposition in which beds of the same age were more eroded to the north than to the south. This is shown by the fact that the present table tops (remnants of this high plain) cut across the slightly tilted edges of the Oligocene beds, so that they are capped by the Pierre shale in the region northeast of Scenic, as near the mouth of Sage Creek, the Titanotherium and Oreodon beds farther south (71 Table, Hart Table, etc.), and by the Leptauchenia and Rosebud beds still farther south (Sheep Mountain, Cooney Table, and the high plain south of White River. This may have been due to a relative depression of the southern portion of the area or relative uplift of the northern portion. After a long period of erosion, during which over 400 feet of sediment were removed from the northern portion of the area, there followed a short period of sedimentation partly of flood-plain character which supplied the 8 or 10 feet of alluvial material which cap the table lands of the region, and rest unconformably on the older White River clays, whose uptilted edges it truncates. Part of this alluvium may have been deposited by eolian action as a prairie loess. The surface of the plain at this time can be pictured by viewing the slightly rolling grass-covered prairie on any of the high table lands above Scenic. For instance, from Cooney Table, which divides White River and Cheyenne River drainage westward from Corral Draw for 15 or 20 miles, it is apparent that Sheep Mountain Table, Hart Table to the north, and the high prairie south of White River,

[99] *Bull. Am. Mus. Nat. Hist.*, Vol. 23, p. 169, 1907.

[100] Todd, Bull. No. 4, S. D. Geol. Survey, 1898, pp. 43–68.

and other distant table lands in all directions, are all parts of an old gently rolling plain. On the sketch map, Fig. 1, the distribution of the remnants of this old plain are indicated by diagonal shading. Data are not yet available for the certain dating of this plain.

Dissection of the High Plain and Gravel Deposition.—After the deposition of the surface alluvium a period of rapid erosion ensued. This must have resulted in the entrenchment of the rivers in narrow valleys or canyons. At this period the rivers possessed great power both of erosion and transportation, as they moved pebbles and small boulders from the pre-Cambrian core of the Black Hills fifty to eighty miles out on the plains, where they are found in the White River valley as far down as Interior. Many of these pebbles have diameters of 8 inches to a foot, and all are stream worn and frequently chatter-marked. They are quite locally distributed on the surface of the badland clays, in some localities being so abundant as to form a layer one or two pebbles deep on the surface, while elsewhere not more than 100 yards removed they may be entirely absent. The general trend of these gravel channels is toward the east or southeast, and their materials are very varied. Colorless quartz, rose quartz, feldspar, pegmatites showing muscovite and tourmaline, mica schists and quartz schists, Cambrian quartzites with *Scolithus* borings, Mississippian gray limestones (Pahasapa) with fossils resembling *Straparollus utahensis, Orthotetes inflatus, Camarotœchia* sp., and *Menophyllum excavatum,*[101] and purplish limestones without fossils resembling in appearance the Permian Minnekahta, and softer sandstones, probably of the Cretaceous Dakota-Lakota series are included. Many of the pebbles show a high polish resembling the so-called desert varnish. Ward [102] describes these surface gravels in the Interior section and believes them derived from Protoceras channels of which no other traces now remain. The possibility that these gravels were derived from some of the conglomerates of White River age has been considered by the writer, but not favorably, for pebbles four or five times the size of those generally observed in channels of White River age predominate in these gravels, which are regarded as more

[101] U. S. G. S., Monograph XXXII., "Geol. of Yellowstone Nat. Park," Part II., Plates ———.

[102] Op. cit., pp. 31–33.

recent than the formation of the High Plain and earlier than the Cheyenne River (South Fork) because the latter at present takes all of the sediment from the Black Hills toward the northeast, while these old gravel channels are found far down in the valley of White River. Those found along White River can not be terrace gravels of the modern stream because their pebbles are all derived from the Black Hills, and the present White River does not drain any part of the Black Hills. It would be of interest to know whether or not these gravel beds also crossed White River, but as no work has been done by the recent Princeton expeditions south of White River, the writer can present no evidence on this point.

After the initial stage of river dissection, the materials carried were probably of finer grain and no trace of these later deposits has been observed. There is evidence of terrace formation in isolated flat-topped buttes, such as those along the divide between Indian Creek and Little Corral Draw, which are from 100 to 200 feet lower than the level of the earlier high plain. There must have been a great deal of erosion at this time, and the rivers may have reached a stage of early maturity, when downward progress was interrupted by a more arid cycle. This aridity is indicated by sand dunes mantling an irregular erosion surface of the Oreodon beds at many points. Sand-dune deposits are found on the two isolated flat-topped buttes near the head of Indian Creek mentioned above, and in the line of hills extending east and southeast from Sheep Mountain, and south of Arnold's ranch, where the belt of sand hills is about a mile wide and six or seven miles long.

The coarse gravels which have just been discussed are found in the upper part of the valley of Quinn Draw and about 15 or 20 miles to the northward in the valleys of Indian Creek and Bear Creek, west and north of Scenic. The Bear Creek gravel stream extends through a low gap into the basin of Cain Creek (a tributary of White River) about four miles northeast of Scenic, near the locality where Thaddeus Culbertson made the first collection of fossils from the White River Badlands (*F* on the index map). The general line of sand-hill ridges is roughly parallel to the two stream courses indicated by these gravel beds (east-southeast) and lies about half way

between them, representing wind-drifted material along the divide between these two streams.

The Capture of the Black Hills Drainage by the Cheyenne River and the Recent Erosional Stage.—The next stage of the history of the region was the formation of the modern Cheyenne River, or South Fork of the Cheyenne. This beheaded all the old streams flowing eastward from the Black Hills to the White and Bad Rivers, including those in which the above-mentioned gravels were laid down, and since then the region east of the Cheyenne River has been mainly subject to erosion. The tributaries from the White River and the Cheyenne have dissected the old high plain so completely that it is now preserved only as the various tables and isolated buttes. This erosion has not been uniform, but has been accelerated and retarded by climatic oscillations toward more arid or more humid extremes. When the rainfall is greater than the average, grass and the prairie vegetation begins to work up over the steeper slopes and erosion is greatly retarded, the streams silt up their channels, and flow almost on the valley floor. Then a few years of diminished rainfall kill off the vegetation, the rain in torrential downpours removes the soil, and active dissection again predominates. The streams cut deep, narrow channels with vertical banks in their valley floors, and the older valley bottom is left as a terrace along the side. In the modern badland draws several successive terraces are often visible. In the valley of Bear Creek three terraces were observed along the modern stream. Each one was about 6 or 8 feet in height. These are only minor fluctuations or rhythms of the climate, and may represent periods of only a few years or centuries. There is at least one major break in the erosional history of the Cheyenne River when broad basins seem to have been developed in all of the creek valleys with nearly level floors. The level of this plain is about the top of the Titanotherium beds or the base of the Oreodon beds. Scenic Basin is an example of this type which is still mostly uneroded, though Spring Creek and Bear Creek have begun its dissection. The valley of Indian Creek shows clear evidence of the same plain, in the uniform level of the tops of the rounded Titanotherium ridges. The old basin floor in Indian Creek has been largely dissected, so that the

draws of today flow at a level 100 to 200 feet below it. Plate II., Fig. 2, is a photograph taken on the level of this terrace in Indian Creek, showing the uniformity of levels in the tops of the buttes. The high buttes in the left distance are capped by a sand dune deposited as described above.

Huntington [103] has discussed fully the origin of terraces and shows that while they may be of either tectonic or climatic origin, the actual structures of the terraces would generally demand crustal movement of very unequal distribution acting differently on different parts of each valley and on adjacent valleys, while a climatic change over the whole area more easily explains all the phenomena.

For the terraces formed by the erosion of the remnants of the old high plain by the tributaries of the Cheyenne and White Rivers, a climatic origin is probable, since all the streams seem to show evidence of the same stages of terrace formation. All of the streams now seem to be entrenched in narrow central channels, indicating that the present is a period of greater aridity than usual. The erosion of the high table lands is progressing rapidly and in many places landslips have dropped the outer few feet of the edges of the tables down into the lower badlands. Sometimes this slumping gives rise to temporary ponds, such as are developed in Cedar Pass at Interior, where extensive landslides of the southern face of the Wall of the Badlands have blocked the channels of two or three badland draws.

Causes of the Capture of Black Hills Drainage by the Cheyenne River.—Todd [104] in a paper on the hydrographic history of South Dakota suggests that this took place before the Pleistocene because of the amount of erosion since that time by the Cheyenne River. He suggests as causes: "(1) the greater rainfall in the northern Hills; (2) the thinness of the Tertiary beds and more easy erosion of the Pierre shale underlying; (3) the capture of the headwaters of a stream flowing northwards, perhaps the Little Missouri." From the evidence given above it seems that the date of the South Fork of the Cheyenne may be as late as the Pleistocene because of the length of time required for the stage of peneplanation, dissection, gravel deposition, and desiccation described above, which took place between the

[103] "The Climatic Factor," Carnegie Inst. Pub. No. 192, 1914, pp. 23–36.

[104] *Bull. Geol. Soc. Amer.*, Vol. 13, 1902, pp. 31–32.

close of Middle Miocene deposition and the beginning of the Cheyenne River period.

Assuming that the date of the stream capture of the southern Black Hills drainage by the Cheyenne River is in the Pleistocene, there are three possible causes for this capture in addition to those mentioned above by Todd. First, there is evidence that many areas were depressed by the weight of glacial ice. The slope of the South branch of the Cheyenne is in general toward the nearest part of the glaciated region east of the Missouri River. This might be due to a change in the direction of regional slope through the depression of the region under glacial ice. On the map (Fig. 10) it is shown that two other rivers have courses almost parallel in direction to that of the south branch of the Cheyenne. These are the lower part of the Little White River and the upper part of White River. (1) Todd [105] says that there is evidence of an old channel from the sharp northward bend of this river to the Minniechadusa, a tributary of the Niobrara, and that the lower northeastward flowing portion of the stream runs through a narrow canyon for several miles with falls. (2) The upper portion of White River is also parallel in direction to the south fork of the Cheyenne, though the writer has no information as to the date of this valley.

In the northern Black Hills there is also evidence of a general tilting toward the northeast. Mansfield [106] states: "The persistent offsetting of drainage in such a manner as to develop northeast-flowing master streams is not satisfactorily explained by climatic oscillations alone, and appears to indicate northeast trenching." He also recognizes a period of post-Oligocene incision or valley formation, followed by a later period of aggradation when extensive boulder and gravel deposits were formed. He interprets this as a period of relatively high humidity (degradation) followed by a return to more arid climatic conditions (aggradation). This seems to correspond to the beginning of the dissection of the High Plain in pre-Cheyenne River time, followed by the period of heavy gravel deposition in the Big Badlands referred to above, and suggests that these stages may represent significant climatic changes over wide areas.

[105] Op. cit., p. 32.

[106] Mus. of Comp. Zoöl. at Harvard Coll., Bull. 49, 1905–08, pp. 71–76.

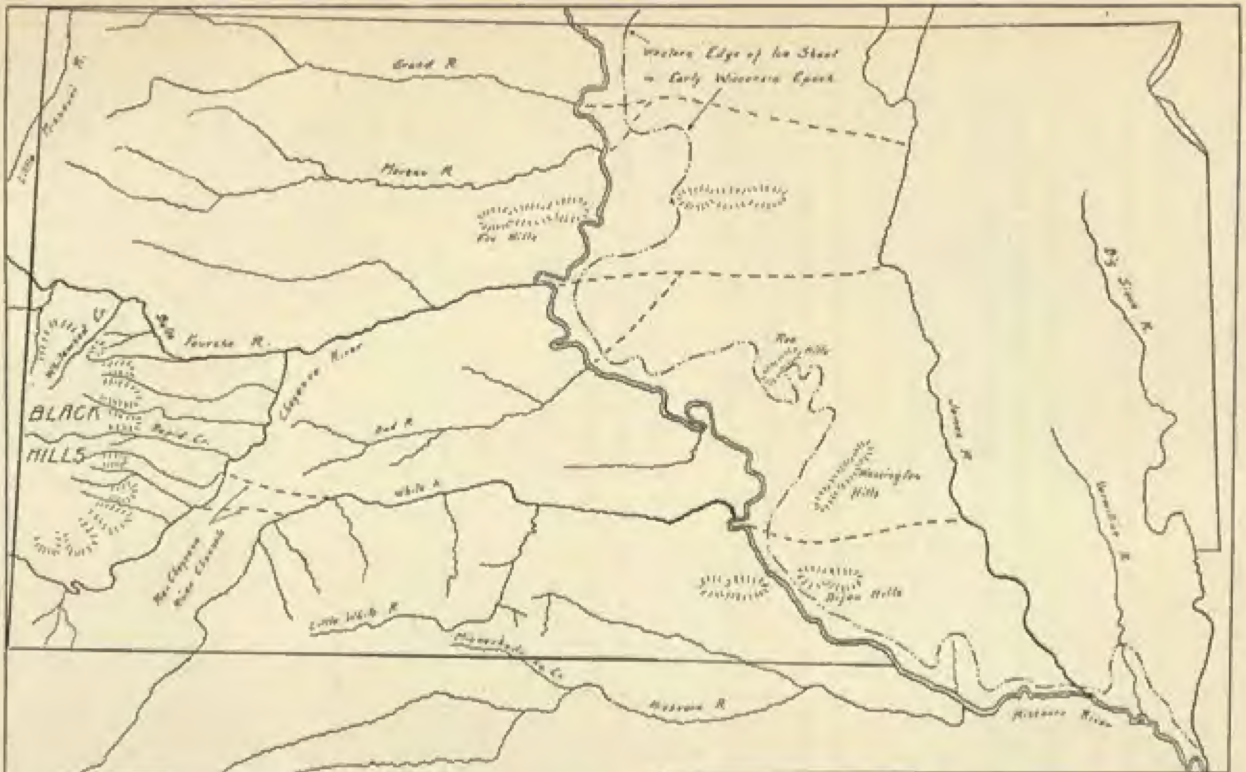


FIG. 10. Map of the drainage of South Dakota, illustrating (1) the stream capture by the Cheyenne River of the drainage of the eastern flank of the Black Hills, which formerly flowed into the White and Bad Rivers; (2) the courses of the pre-Cheyenne River streams now represented by gravel beds, between the Cheyenne and White Rivers; (3) the pre-glacial courses of the Grand, Moreau, Cheyenne, Bad, and White Rivers, east of the present Missouri River, the outlying remnants of the old divides between these rivers, east of the Missouri, and the western edge of the ice sheet in the early Wisconsin epoch; (4) the northeastward courses of Whitewood Creek and the lower part of the Little White River, which have recently captured streams which flowed in an eastern or southeastern direction. Scale 60 miles = 1".

A second possible cause for the capture of the Black Hills drainage by the Cheyenne might be the fact that the Missouri was forced westward nearly 200 miles in central South Dakota by the glacial advance. It had previously flowed in the valley now occupied by the James River in eastern South Dakota. There are remaining east of the Missouri the continuations of high divides between the valleys of Bad River and the Cheyenne, and the White River and the Niobrara (Bijou Hills), showing that these streams flowed eastward beyond the present valley of the Missouri. The course of the Cheyenne River between the Black Hills and the Missouri was shortened more than that of the White River when the Missouri was forced westward around the end of the glacial lobe. Similarly the course of the White River was shortened more than that of the Niobrara. The increased gradients in each case may have stimulated headward cutting of the tributaries, so that they were able to capture the headwaters of streams less favored.

A third cause which may explain the stream capture by the Cheyenne River and the almost complete erosion of the Tertiary deposits from central and northwestern South Dakota, is what Huntington & Visher [107] have described as the shifting outward of a belt of great storminess around the end of a glacial lobe, which is a permanent area of high barometric pressure. If the belt peripheral to the edge of the glacier in central and northern South Dakota received a greater number of storms which had formerly passed north of them, the rivers of this belt, especially the Cheyenne, would be stimulated to more active channel cutting and might easily lower its bed so as to capture the headwaters of streams less favorably situated, as the White and Bad Rivers. The geographic relations seem to suggest some relation between the recent erosional history of the region and the glacial lobe to the east of the present course of the Missouri River through South Dakota.

From the foregoing outline of the post-White River history of the badlands of South Dakota, it is apparent that the series of climatic rhythms traceable in the Oligocene continued in increasing magnitude through the late Tertiary and Pleistocene to the present. It is not

[107] "Climatic Changes," 1922, pp. 110–129, 141–144.

yet possible to interpret these rhythms entirely nor to correlate them with rhythms in other parts of the western United States or the world, but a careful study of the climatic history of different areas may lead to the recognition of many world-wide climatic cycles of lesser magnitude than glacial periods, but still sufficient in size to have a profound influence on the distribution and development of the plant and animal life of the world.

SYMPOSIUM ON THE INHERITANCE OF ACQUIRED CHARACTERS.

HISTORICAL SKETCH.

By WILLIAM B. SCOTT.

(*Read April 21, 1923.*)

My function this afternoon is to act as a prologue; and, in the first place, to explain to those of you who are not biologists precisely what the problem is, and, in the second place, to give a brief historical outline as to the course and fluctuation of opinion with regard to it.

The problem may be briefly stated thus: Whether the characters which are acquired in the lifetime of a parent are transmissible to the offspring. Acquired characters are those with which the individual is not born, or hatched, or otherwise brought into the world, nor such as would normally develop at certain stages of life. A man, for example, is born without a beard, but a beard can not be regarded as an acquired character, it is merely an illustration of what Darwin called "inheritance at corresponding stages of life." Acquired characters are modifications peculiar to the individual. There is no question at all that congenital characteristics, those with which the individual is born, are largely transmissible. The doubt comes as to whether such modifications as arise in the organism, due to injury, accident, disease, or the habits of life, are ever passed on, in however slight degree, to the offspring.

Many savage tribes practice mutilation of one kind or another, or deformation of children. The Flathead Indians, for example, distort the heads of their babies, and for centuries the women of the upper class in China have had their feet distorted by binding. Then again aptitudes and habits are, especially in the oriental countries, practiced by the same family for many centuries. Is there any evidence that the children of those families, aside from early training, more easily acquire skill and attain a higher degree of it than the children of families in other handicrafts? It must not be supposed

that all acquired characteristics are of the nature of those previously mentioned. They may be structural, as the result of use or disuse on the part of the individual. Parts which are not used at all tend to shrink and atrophy, while those which are regularly and vigorously exercised increase. Are such effects ever heritable?

Now, without taking sides, pro or con, it remains for me to sketch briefly the course of scientific opinion on this topic.

For a long time the transmissibility of acquired characters was taken for granted, and the great difference between the views of Lamarck and those of Darwin was as to the importance in the causation of evolutionary changes which was to be attributed to such transmission. Lamarck gave much higher importance than did Darwin to these individual changes and acquisitions. Nevertheless, Darwin explicitly accepted the heredity of acquired characteristics, and repeatedly calls in the facts of use and disuse to explain the course of development. In one famous chapter he compares the skeletons of wild and domestic ducks, and shows that in the latter the bones of the wings are relatively smaller than in those of their wild progenitors; and he explains this difference by the fact that the domestic duck uses its wings but little, or not at all. In order to explain the transmission of such characters from generation to generation, Darwin devises an elaborate theory of heredity, the theory of Pangenesis, though this never found any considerable degree of acceptance. It must also be recognized that Darwin attributed a distinctly secondary importance to the acquisition of individual characteristics and their inheritance by subsequent generations. To him the all-important changes were the congenital variations with which the individual was born. Nevertheless, it is distinctly unfair and inaccurate to insist that the theory of the transmission of acquired characters is purely Lamarckian and not Darwinian. The difference between these two illustrious men in this regard was as to the degree of importance which should be attributed to this process.

It has long been known that cave animals of various classes, fishes, amphibians, insects, and spiders, which live in total darkness throughout their entire lives, are nearly always blind and without pigmented color. This general phenomenon (which is also largely,

but not exclusively, shared by the creatures of the deep sea) was formerly attributed to the direct action of the darkness itself upon successive generations of these cave animals; and this, acting cumulatively, produced the effect of blindness and lack of pigmentation; and a more typical instance of the supposed transmission of acquired characters could hardly be selected than this.

An entirely different aspect was given to the whole question by the publication, from 1889 to 1892, of the various essays of the late Professor Weismann, of Freiburg, in Germany. Weismann's career was quite a remarkable one. Beginning with the microscopic work, then universally expected of every German professor of zoölogy, he was forced by failing eyesight to take to other lines of work; and he published the results of a series of experimental investigations upon butterflies, amphibians, and other creatures, which were gathered up and preserved in book form, and published in England with a preface by Darwin. This work was followed by a remarkable series of speculations upon the constitution of the germ plasm—*i.e.*, the wonderful material which is the carrier of heredity. To a certain extent, Weismann's view as to the continuity of the germ plasm was anticipated by Sir Francis Galton in England, who compared the germ plasm to the chain of a necklace, and the individual to the pendant hanging from each link.

The work of Gregory Mendel, the famous Austrian monk, which was published in 1866, was so far ahead of its time that it fell dead-born from the press, and was altogether forgotten until Mendel's results were rediscovered by the German and Dutch botanists. Weismann thus knew nothing of Mendel's work; and it is very surprising to see how, by a process of pure speculation, he reached very similar results. Time would fail to give any, even the briefest, account of Weismann's views as to the constitution of the germ plasm, nor is it necessary in this connection. It will suffice to say that Weismann was led to deny, in toto, the possibility of the transmission of acquired characters, not from experiments or observations upon that particular problem, but because his theory of heredity could provide no machinery for such transmission. He thus became an extreme Darwinian, in the narrowest sense of the word; and one of his papers

bears the title "The Omnipotence of Natural Selection," which he regarded as the sole active factor in organic development. Weismann's views speedily found a very wide acceptance throughout the world; and it is probable that the overwhelming majority of botanists and zoölogists would today deny the possibility of the transmission of acquired characters. Even the medical men speedily accepted the same conception of the heredity of disease. Aside from cases where the unborn child is directly infected, it is now largely maintained that what is transmitted from parent to child is the liability to a particular disease, and not the disease itself—the constitution which lays the individual open to infection.

For years past in many quarters the question has been regarded as definitely closed and settled, but it will not down; and in some of the testimony which you will hear in the course of this symposium you will see the reason why this problem remains one of sempiternal interest.

It is not for me to express any views on the problem itself; but I trust that in this brief outline you will get an idea of the proportions which this problem has assumed in the history of biological thought.

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THE GERM-CELL AND SEROLOGICAL INFLUENCES.

By M. F. GUYER.

(*Read April 21, 1923.*)

Distrust of the earlier naïve belief in the wholesale inheritance of any or all modifications which might be acquired by the body was the necessary prelude to the later doctrine of germinal continuity which has proved to be such a remarkable incitant to research in the fields of embryology, cytology, and genetics. As an outcome of this research one important discovery has followed another until today we have before us in these several realms an imposing body of interrelated facts. But in our effort to root out the cruder Lamarckian heresies, is it not possible that we have been more zealous than our actual knowledge warrants?

Knowing as we do today that the germ-cells and the body-cells of a given organism usually develop at the same time, all descending by division from an initial fertilized ovum, it is obvious that the new organism is, in the main, the expression of what is in the germ-line rather than of what it got from the body of its parents. Since the new germ-cell is but a reduplication of the zygote from which it sprang, it is not astonishing that it should express itself structurally and functionally in the same way.

The real problem in which the evolutionist is interested, however, is not so much that of how metabolic activities already established are handed on and expressed in descendants, as the problem of how new complexes which find expression as new or modified characters originate in the germ. Are they the result of constitutional germinal changes which bear no direct relation to the investing soma or the extrinsic conditions of life, or are they initiated by somatic or other environmental influences? If the latter, is there any specific relation between the stimulus and the result it produces? Or, again, are there perhaps at one time inner, at another outer causes, or combinations of these responsible for the results? In any event it is evident, as Darwin long ago pointed out, "that the nature of the organization

acted upon essentially governs the result." It is, in brief, this fact of change, of variation, that is the real basis of evolution, and the problem of problems is that of the cause or causes of such changes.

For, as I have expressed the matter in an earlier paper,[1] "whatever we may believe about the degree of preformation which exists today in the mechanism of heredity, it is absurd to assume that in the simpler primitive protoplasm from which modern forms have evolved there could have been genes of the characteristics of all the organisms now in existence. Whatever individual development may be, we must assume that racial evolution was epigenetic. While doubtless in a sense man lived potentially in some primitive protozoan-like creature, actual material antecedents of his existing attributes were no more present in this ancestral creature than specific determiners for the oceans, continents, and topographical features of the world today were present in the original nebula which preceded our solar system. The great central problem of evolution is just this very one of how the determinative accumulations which exist in germ-cells today have been incorporated step by step into this erstwhile primitive protoplasm. Certain possibilities have become realities and concomitantly as a basis of this reality the old mechanism has in part been altered, or a new mechanism has come into being which persists as a part of the established constitution of the germ-cell."

Before proceeding to further consideration of this matter, perhaps it will not be unprofitable to question briefly a few of the stock arguments commonly brought forward in support of the belief in the non-inheritance of somatic acquirements—or to state it more truthfully, in disparagement of any belief in the inheritance of such modifications. It is a noteworthy fact that these arguments are mainly in the nature of denials, and while no one can question the value of corrective criticism, yet we sometimes need reminding that no convincing edifice of positive truth can be built wholly of negations. Success in pointing out the shortcomings of a rival theory by no means establishes the correctness of our own.

One argument commonly advanced is the impossibility of a somatic modification, such as a change in the brain structure or in the

[1] *Am. Nat.*, Vol. LVI., Jan.–Feb., 1922.

biceps muscle, being specifically registered in the germ, since the latter is a cell possessing no such organ, but merely the possibility, after repeated divisions and growth, of producing the organ. But is this a fair way of stating the matter? Any organ of the body is a congeries of cells, each as much a lineal descendant of the original fertilized ovum as the most immaculate germ-cell, and we have no reason to believe that somatic cells any more than germ-cells lose the hereditary potencies of the original zygote.

Experimental morphology has shown that the distinctive structural effects and functions which characterize the respective tissues, of many organisms at least, are probably the outcome of unequal activities among the same kinds of fundamental protoplasmic constituents in differing local environment; or in other words, in such forms a particular cell takes on the characteristics of a specific tissue, not because it is constitutionally different from other cells, but because of the differential nature of the stimuli to which earlier it has been exposed or to which it is subjected as a result of its special location in the developing organism. The innumerable phenomena of heteromorphis, shifts of axial gradients, metaplasia, compensatory vicarious adjustments and the like, which make up the commonplaces of experimental morphology and pathology, all abundantly bear witness to the fact that the same initial cellular materials may yield very different end-products in different environments; that many, possibly all, cells retain all of the capacities for differentiation that existed in the original zygote. If we are to make a just comparison, then, between an organ and the germ, it should be a comparison between the individual cells which compose that organ and the germ-cell. As soon as we do this the matter takes on a very different aspect. For while various tissues may differ much in appearance, this is probably due mainly to cytoplasmic modifications or the accumulations of intercellular products—that is, to differences in the formed products of the protoplasm—rather than to fundamental differences in the living protoplasm itself of the respective cells. If, then, changes in a given organ can release or engender products that operate specifically on certain elements in the component cells of that organ, it certainly puts no undue strain on our credulity to suppose that, granted some sort

of circulating medium, these same products may reach and act similarly on the representatives of these elements in the germ-cells.

We are also told that for a new character to be demonstrable as an inherited acquirement it must be capable of reappearing in successive generations without the recurrence of the original evocative stimulus. But is this, at least without some qualifications, wholly a just demand? For a character which might be the chance sport of a non-specific extrinsic influence perhaps the requirement is a fair one, but why should an adaptive character which may have arisen in adjustment to a special environment necessarily reappear, at least in its full expression, if the conditions to which it has become adapted no longer exist? It is a biological commonplace that any organ which is prevented from functioning remains underdeveloped or even atrophies. Supposing, for example, that the effects of muscular training were in some degree inherited, the inborn increment for greater strength in the descendants of an ancestry of athletes would not reveal itself unless such progeny performed at least a certain modicum of muscular work.

Again, we are sometimes referred to the results of the ingenious and interesting transplantation experiments of Castle and Phillips as proof of the non-inheritance of somatic acquirements. If we accept the presence-absence hypothesis as, judging from their publications, some Mendelists do, then, in guinea-pigs, black is dominant to white in crosses of black individuals with albinos because the offspring receives a factor for pigmentation from the black parent, but none from the white parent, and a single gene for pigmentation is sufficient to make the hybrid black. So that when Castle and Phillips transplanted the ovary of a black guinea-pig into a white female whose own ovaries had been previously removed, and then bred this white female to a white male, they got what anyone, whether he be believer in the transmission of somatic acquirements or not, would expect them to get, namely, black offspring. For obviously such progeny must spring from ova carrying the factor for pigmentation, and since, according to the presence-absence hypothesis, the albino whiteness in question is due to absence of a pigment factor, there is nothing in either the white male parent or the white female foster-parent that

could be expected to operate on the ovarian gene for black to modify it. He would be a sanguine transmissionist, indeed, who would expect *nothing* to operate on *something* and produce a change!

But even if we follow what seems to be the present-day tendency and abandon the presence-absence hypothesis as an unjustified assumption, we are no better off in such transplantation experiments. For, if albinism is represented by an actual positive factor in the germ which, nevertheless, remains unexpressed when associated with a factor for pigmentation, then why should we expect such a factor for albinism in the body of a foster-parent to affect a factor for pigmentation in the implanted ovary, any more than we should expect albinism introduced by one gamete to affect the factor for pigmentation carried by the other gamete?

In general, the persistence of Mendelian recessives is widely regarded as convincing evidence against the theory of possible somatic influence on inheritance. The inference is, I take it, that once such recessives become obscured, their factors should disappear if the body can influence the germ. But why should they? Even granting somatic influence, why should not the factors for recessives persist indefinitely in the germ unless the somatic changes in question have some direct bearing upon them? It seems to me that this argument based on persistent recessives is largely beside the point. It would be valid against the old theory of pangenesis advanced by Darwin, which looked upon the new individual as an assemblage of samples collected from the tissues of the parent, but nobody advocates any such theory today. The idea that the constituents of the germ might be influenced by direct environmental conditions or by something transported to the gonad in the circulating fluids of the body is a very different one from the idea that the germ is constructed anew in each generation by aggregations of gemmules from the various parts of the body. The one conception involves merely the modification of a mechanism already existing, the other implies recreation of an entire germ in each generation.

Lastly, the fact that germ-cells and soma cells of a given individual often arise simultaneously in embryogenesis, and that neither produces the other, is commonly regarded as evidence of the inde-

pendence and genetical self-sufficiency of the germ, and of the reproductive impotence of the body. The contrast is heightened by pointing to the few striking cases we are acquainted with in which the germ-cells are so conspicuously set apart in early cleavage that their history may be followed throughout later development. Not infrequently we forget to add that in some species of animals, at least, there is evidence for believing that these primordial germ-cells later retrogress and disintegrate, and that the functional germ-cells which succeed them are of uncertain origin. Even blinking the well-known facts that in plants and in lower animals somatic cells readily give rise to new individuals, and that in some plants the somatic cells may be stimulated into the production of genuine germ-cells, the fact that in some forms germinal tissue apparently arises independently of the somatic tissues does not necessarily carry with it the implication that the investing soma can have no effect on the germ. In thus conceiving of such isolation for the germ are we not in effect expecting it to exercise the quasi-spiritual prerogative of being in this world, though not of it?

And so we might submit various of the other classical arguments against belief in the inheritance of somatic acquirements to the test of analysis and find that such generalizations, though well-sounding, are not as impregnable as the assurance with which they are usually expressed might lead one to suppose. Taken all together, however, they unquestionably supplement one another and constitute a body of evidence which renders it improbable that somatic acquirements are passed on to the germ constantly or with great frequency, at least to any considerable degree, in one or a few generations.

Before entering upon the question of whether or not serological activities may be possible or probable sources of germinal modifications, we may recall briefly certain facts of the immunologic reactions. Foreign proteins of either plant or animal origin introduced into the blood-stream of an animal will cause the formation of certain antagonistic or corrective substances to which the general name of *antibody* is applied. The protein substance employed to produce antibodies is commonly called the *antigen*. Although there are several classes of antibodies—precipitins, agglutinins, bacteriolysins, cytolysins or cyto-

toxins, etc.—they all have certain points of similarity, as, for instance, their means of origin, their reaction to heat, and, in some cases, their mode of operation. Chemically their natures are still unknown, although evidence of their association with the euglobulin fraction of the blood is appearing in various recent investigations.

In our experiments we have occupied ourselves mainly with agglutinins, precipitins, and cytolysins or cytotoxins. Agglutinins, as the name implies, are agglutinating substances. Bacterial agglutinins, for instance, clump bacteria of the species used in their production, if the two are brought together in the blood-serum of the animal into which the bacteria were originally introduced. Precipitins are substances which form a precipitate when the blood-serum of the treated animal and an extract of the tissue used as antigen are brought together in vitro; and cytotoxins or cytolysins are antibodies which possess a toxic or solvent action for the kind of protein used in their production.

In the main all of the immunologic reactions show a considerable degree of specificity; the antibody will react fully only with the particular kind of protein used as antigen. The specificity is not absolute, however; a milder reaction may be obtained with homologous proteins of related species, the extent of the reaction being determined by the nearness of relationship of the species to that from which the original antigen was obtained. With bacteria, the reaction is in the main specific, although so-called group reactions may appear. The serum of an animal immunized against typhoid, for example, may not only agglutinate *Bacillus typhosus,* but may also show this reaction in a less degree with such related forms as the colon bacillus.

Before leaving this subject of specificity, it should be further pointed out that a so-called "species-specificity" and an "organ-specificity" are recognizable in certain serological reactions. By species-specificity is meant the fact, shown through precipitin reactions, that blood immunized against one tissue taken from a given species of animal will react, although in a less degree, with extracts of the other tissues of that species. Thus the blood-serum of a rabbit which has been treated with sheep blood-serum will form a precipitate not only with sheep-serum, but to some extent also with extracts of

sheep-muscle, sheep-liver, sheep-spleen, and other organs of the sheep. On the other hand, that there may be organ-specificity also, is shown by the fact that immunization with crystalline lens of one species of animal yields a precipitin which reacts with the lens proteins of various other species. Here again, however, the reaction against the kind of lens used as antigen is stronger than against the lens of a different species of animal, so that even in cases of organ-specificity there is still a demonstrable individual specificity. In our experiments we find, for example, that with extract of pig-lens, the serum of a goat immunized against pig-lens yields a much heavier precipitate than does this same serum when tested with extract of rabbit-lens.

Coming now to our main problem, if it is possible to originate in living animals antibodies which will modify or destroy particular elements in tissues, is it not possible to secure similar selective action on the parts of the developing embryo? Or may there not be sufficient constitutional identity between the constituents of the somatic cells and those of the germ-cells that the latter may be specifically modified by such serological influences as can provoke specific changes in tissue-elements?

In an attempt to find answers to questions of this kind, my research associate, Dr. E. A. Smith, and I began various experiments with lens antibodies and with *Bacillus typhosis* some years ago, which we are still continuing. Although we have experimented with mice and guinea-pigs, our main work has been with rabbits. At first, in the lens work, fowl-serum immunized against rabbit-lens was employed, but later we injected pulped lens-material directly into the rabbits, and experiments are now in progress in which sheep instead of fowls are being used as the source of antibodies. I may narrate briefly the account of certain eye-abnormalities secured in fetal rabbits and the facts concerning the transmission of such defects to subsequent generations.

In our first experiments [2] the lenses of newly killed young rabbits were pulped thoroughly in a mortar and diluted with normal salt solution. About four cubic centimeters of this emulsion was then injected intravenously or intraperitoneally into each of several fowls.

[2] *Jour. Exp. Zoöl.*, Vol. 26, May, 1918; Vol. 31, Aug., 1920.

Four or five weekly treatments with such lens-emulsions were given. A week or ten days after the last injection the blood-serum of the fowls was ready for use. The rabbits had been so bred as to have their young advanced to about the tenth day of pregnancy, since from the tenth to the thirteenth day seems to be a particularly important period in the development of the lens; it is then growing rapidly and is surrounded by a rich vascular network that later disappears. From four to seven cubic centimeters of the immunized fowl-serum were injected intravenously into the pregnant rabbits at intervals of two or three days for from ten days to two weeks. A number of the rabbits died from the treatment and many young were killed in utero. Of sixty-one surviving young from mothers thus treated, four had one or both eyes conspicuously defective and five others had eyes that were clearly abnormal. It is possible that still others were more or less affected, as we judged only by conditions easily visible. In some of the descendants of this stock, indeed, ophthalmologists who have examined the eyes more thoroughly have pointed out defects which we had overlooked, and occasionally rabbits, that in their earlier months passed for normal, have later manifested defects in the lens or in other parts of the eye.

The commonest abnormality seen in both the original subjects and in their numerous descendants was partial or complete opacity of the lens usually accompanied by reduction in size of the eye. In a few of our later strains in a different experiment, however, we have had several cases of enlargement of the eye, or *buphthalmia*. Other common defects which have appeared are cleft-iris, displacement of the lens, persistent hyaloid artery, bluish or silvery color instead of the characteristic pink of the albino eye, microphthalmia, and even almost complete disappearance of the eyeball. The cases of cleft-iris, or *coloboma*, range all the way from a narrow slit in the lower edge of the iris to a broad wedge- or U-shaped opening which amounts practically to the absence of the entire lower part of the iris. The cleft may be confined to the iris or it may extend back deeper into the eye. When one takes into account the early embryology of the eye, it is easy to see how such clefts result from failure of the choroidal fissure to close as it should do normally. The bluish or silvery color, I am

told by ophthalmologists who have examined the rabbits, is due mainly to detachment of the retina. Here again, when one recalls the loose embryologic connection between the retinal layers of the eye and the outer coats, even in the normal eye, it is easy to see how almost any distortion of the eyeball, unevenness of growth, or accumulation of fluid might bring about such detachment.

Many of the eyes take abnormal postures. This is particularly true in some of our later strains. One or both eyes are likely to be strongly rotated downward or backward. The backward-rotation is carried to such an extreme in some cases that the cornea is visible only when the eyelids are drawn back at the outer corner or occasionally when the animal attempts to roll its eyeball forward. In such eyes the exposed sclera in front usually bulges (*staphyloma*) and becomes transparent, simulating a cornea. When we first came across this anomaly, in fact, we thought that we had a rabbit with a double eye on each side.

Taking into account the method of embryologic development—the relations of lens, optic cup, and choroidal fissure—the defects, except those of the muscular attachment, are practically all such as might reasonably be attributed to arrests of development based upon early lens-defect. It is possible, to be sure, that we have developed antibodies against other eye-tissues as well as against the lens, since undoubtedly more or less of the aqueous humor and the vitreous body adhered to the lenses when we removed and pulped them for the original injections. Moreover, if proteins from other parts of the eye are ever in solution in the humors, they, too, may have been present in the antigen. Each individual protein, of course, has the capacity for engendering antibodies specific for itself.

In some of our animals we find that an eye defective at birth, particularly if microphthalmic, may undergo further degeneration, characterized by collapse of the eyeball and resorption, so that the eyeball may eventually disappear entirely. The eyes of the mothers originally injected have always remained apparently unaffected. This is probably due to the fact that the lens-tissue of the adult is largely avascular, and that, therefore, the injected antibodies did not come into contact with it.

That the changes in the eyes of the fetuses resulted from the specific action of lens-antibodies is indicated by the fact that in the original experiment, in not one of the forty-eight controls obtained from mothers which had been treated with pure fowl-serum or with fowl-serum immunized to rabbit-tissues other than lens was there any evidence of eye-defects. I may add that since then, among over five hundred young obtained from mothers which are being experimented upon for other purposes with various types of sera or protein-extracts, or with typhoid bacilli, just before or during pregnancy, not a single case of eye-defect has appeared. To one familiar with the results obtained by the experimental embryologist, which show how susceptible the eye is in early embryology to any kind of harmful influence, the natural inclination is to regard such abnormalities as due merely to a general poisonous or inhibitive effect, rather than to specific antibodies in the blood-serum. In answer to this I can only repeat that we have never obtained the defects in question except with serum carrying specific antibodies. In any event, should the effect have originally been a general rather than a specific one, it is obvious that, germinally considered, it must sooner or later have become specific, since the anomalous eye-condition appears generation after generation without any recognizable accompanying malformations of other parts of the body.

Before passing on to the question of inheritance, I may say that by way of control, for genetical studies, in addition to what we have termed our 3A1 line, we developed another line from wholly unrelated stock, our so-called 16A1 line. Moreover, we have established still a third strain, the 84 line, which was started, not by means of fowl-serum immunized to rabbit-lens, but by the use of pulped rabbit-lens intravenously injected directly into rabbits just before or during their pregnancy. In this last case the rabbit must herself have developed antibodies against the invading lens-material. Out of eleven different females so treated, in twenty-three matings, only one individual gave us young with abnormal eyes. These defects are of the same general nature as those secured by means of fowl-serum immunized to rabbit-lens, and they behave similarly in inheritance. We have also started a defective-eyed line of guinea-pigs in which the anomaly was pro-

duced by the injection of pulped rabbit-lens into the pregnant mother guinea-pig. And finally, another investigator, working in our laboratory with pedigreed lines of a large variety of rabbit known as New Zealand Reds, has secured defective eyes in fetal young by employing sheep serum immunized to rabbit-lens.

As already indicated, once the defect is secured, it may be transmitted to subsequent generations through breeding. So far, in the 3A1 line, we have succeeded in passing it down through nine generations. There is no reason apparent why it will not go on indefinitely, since the imperfections tend to become worse in successive generations, and also to occur in a proportionately greater number of young. The same genetical conditions hold for the other lines, although because of their more recent origin we have manifestly not been able to carry them through so many generations.

The transmission is not infrequently of an irregular unilateral type, sometimes only the right, at others only the left, eye showing the defect. In this respect it resembles genetically such anomalies as brachydactyly or polydactyly in man. In later generations there has been an increasing number of young with both eyes affected.

The abnormal condition has in general the characteristics of a Mendelian recessive. When either defective-eyed males or females are bred to normal-eyed individuals from other strains, for instance, only normal-eyed progeny result in the first generation, but the abnormal condition may be made to reappear in subsequent generations if appropriate matings are made. Two defective-eyed rabbits bred together, however, are likely to produce some normal-eyed young—a fact which indicates that we are not dealing with a simple Mendelian recessive. Possibly more than one pair of unit factors are involved.

To assure ourselves that the transmission of the defect from generation to generation was not merely the passing on of antibodies by way of the placenta from mother to young, the descent has been repeatedly established through male lines. Females from strains of rabbits unrelated to our treated stock when mated to defective-eyed males always bear normal-eyed young, but when such young are mated to defective-eyed males or to males of their own derivation, the defect reappears in some of the progeny, after the manner of a

Mendelian recessive. It is plain that the abnormal condition could have been introduced into these new strains only through the germ-cells of the defective-eyed males, and its transmission is, therefore, an example of true inheritance.

But if serological influences are of any importance in the production of germinal changes under the ordinary conditions of life, they must be such as arise in the animal's own body without the intervention of man, so it becomes of importance to ascertain whether or not an animal will build antibodies or related substances against its own tissues when these become displaced, injured, or otherwise modified. We have been able to show experimentally that such is the case. In a series of experiments with spermatotoxins, for example, I found [3] that the blood-serum of a rabbit injected intravenously with its own spermatozoa becomes highly toxic for the spermatozoa of rabbits, including its own. And just within the past few days we have been able to demonstrate that a normal rabbit will develop lens-antibodies in its blood-serum when its lens is injured. To determine this we first tested the serum of three rabbits for rabbit-lens precipitins and, in each case, found it negative in all the dilution commonly employed in making the precipitin test. Next, we anesthetized the rabbits and attempted to break up the lens in one eye of each by means of a needle, using the technique commonly employed by the ophthalmologist in similar operations on children. Seven days later the serum of each of the three rabbits was tested for lens precipitins. In one of them positive reactions were obtained in all dilutions up to 160. In the other two the results were negative, but we have reason to believe that the lenses of these animals were not injured in the original operation because they remained perfectly transparent, whereas the lens in the eye operated upon in the first rabbit became opaque within a few hours after the operation. We are planning to repeat this experiment on a number of animals immediately.* As a significant supplementary fact I may add that tests for lens precipitins were made on the blood-serum of certain of our defective-eyed individuals which

[3] *Jour. Exp. Zoöl.*, Vol. 35, Feb., 1922.

* Since writing the above seven rabbits have been treated in the manner described; lens precipitins developed in every case.

had marked hereditary lens-defects and positive reactions in dilutions of from 80 up to 160 occurred.

But if antibodies of the nature of precipitins may thus arise against an animal's own tissues, there is no reason to doubt that other types of antibodies also occur, although their presence is not so easily demonstrated. As a matter of fact, it has been known for some years that toxic reactions resembling anaphylactic shock often follow extensive injuries of the soft tissues. Moreover, some nine years ago Bradley and Sansum, employing anaphylactic reactions, found that guinea-pigs injected with various guinea-pig tissues such as heart, liver, muscle, testicle, and kidney developed immunity reactions. Again, the "sympathetic" degeneration of an uninjured eye, so familiar to oculists, which may result if the other eye is severely damaged and not removed, is strongly indicative of a cytolytic or cytotoxic influence. Also, it is known that certain changes in the blood of the mother during pregnancy, apparently induced by cells or cell-products set free from the newly forming placenta, seem to be of the nature of antibody formation.

The whole subject of the fetal and maternal relationship fairly bristles with question marks, but to consider it on this occasion would lead us too far afield. The problem here merges with that of the endocrinal secretions. The latter are at present such popular subjects of research that it is widely known that in them we have in the circulation a series of powerful substances capable of producing profound effects in any or all parts of the organism. Since hypertrophy or atrophy of an endocrine gland may be followed by marked alterations of structure or function in one or more regions of the body, it seems not unlikely, as various investigators have suggested, that the germinal homologues of the parts of the somatic cells thus affected might likewise be modified. I have enlarged upon this line of thought somewhat in earlier papers [4] and can not enter into it here.

I wish to return now briefly to another line of experimentation we have in hand. As you know, two different opinions, based on the old problem of the inheritance or non-inheritance of somatic acquirements, have been advocated to account for the relative immunity that

[4] *Am. Nat.*, Vol. 55, Mar.–Apr., 1921; Vol. 56, Jan.–Feb., 1922; Vol. 56, Mar.–Apr., 1922.

a race of people or strain of animals develops in time against infectious diseases to which they have long been exposed. According to the one view the partial immunity acquired by such members of the population as recover from the disease is transmitted in some degree to their young. Such of these as again survive infections of the disease develop still greater immunity, which is in turn passed on to their offspring, and thus a racial immunity is gradually evolved. The other view regards such racial immunity as more in the nature of a negatively developed trait which has become the prevalent type because of the death, generation after generation, of the more susceptible members of the population. It is clear that the problem can be settled only by experimentation.

In an attempt to get some light in the matter, we are immunizing successive generations of rabbits to the bacillus of typhoid fever. We chose *Bacillus typhosus* as a test organism because we could easily obtain standardized strains of it from the State Health Laboratory and because rabbits will build up antibodies against it without developing typhoid fever. Furthermore, the Widal agglutination test affords a ready means of determining the degree of immunization which has been attained in any individual. Our experiments have been in progress over three years, during which time four, or in one line five, generations of rabbits have been secured.

Without going into the details of our technique and experiments, I may report simply that in what were originally normal untreated individuals, after immunization to typhoid bacilli we were able to secure agglutination of *Bacillus typhosus* in dilutions of serum with normal salt solution of not over 1:720 or at most 1:1440. In some of our later generations we find individuals which, upon immunization, give us positive agglutinations in dilutions as high as 1:20,000 and even 1:40,000.

We found also that while young of a normal mother nursed by an immunized mother acquire a titer approximating that of the foster-mother and lose it again rapidly after weaning time, young of immunized mothers, even when nursed by a non-immunized foster-mother with negative agglutinin reaction, maintain their titers for some months. This fact leads one to believe that in the offspring

which have acquired their immunity reactions through placental transmission some mechanism concerned with production of antibodies has been influenced which was left untouched by such passive transfers as occur through milk. Furthermore, a spontaneous rise in titer which is likely to occur in from three to five months after birth in such placentally immunized young tends to bear out this conclusion.

It is of interest to learn that uterine young may not only acquire immunity reactions from their mothers, but may retain them sufficiently to transmit them in a measurable degree, without further immunization, to their own offspring. Even if this is nothing more than placental transmission it may be of practical importance, since, in placental mammals, a large percentage of a population might, in time, through such transmission come to exhibit some degree of immunity to a widely prevalent disease.

Lastly, if the results of our future experiments bear out our present data, it becomes evident that when succeeding generations of rabbits are immunized to typhoid bacilli some modification is made in the immunity mechanism whereby individuals of later generations are capable of developing higher titers against these germs than were the individuals of the first generation treated. Whether or not the new condition is truly hereditary—that is, due to factors present in the germ-cell at the time of fertilization—remains yet to be tested. Our present results are suggestive of this. We expect to carry our experiments through several further generations before trying to decide by such genetical criteria as transmission and extraction of the condition through male lines. We are endeavoring in every way to avoid selection, since it is obvious that if we selected for breeding purposes in each generation only those individuals that showed the highest titers, we might merely be taking the place of a " natural selection " which operates on an original natural immunity, or conceivably concentrates various multiple or supplementary factors in successive generations.

In conclusion, I may say that from the combined results of the experiments in the several fields of our studies, and in view of the fact that there are so many agents at large within the animal organism which can modify the cellular constituents of the various tissues, we

feel that it is not unreasonable to suppose that in the serological mechanism of the body of animals there exists a means for the incitement of certain of the germinal changes which underlie evolution. In so far as these seral influences may be engendered through modifications of an animal's own tissues they provide a possible means of reflecting the effects of such modifications onto the germ-cells specifically as hereditary somatic acquirements. For example, if an injured lens originates lens antibodies in the blood which attack some of the lens determining constituents of the germ-cells in such a way that the new animals developed from such germ-cells have defective lenses, then the result must be reckoned an example of the inheritance of a somatic modification. On the other hand, if a seral substance introduced from without or produced by the introduction of foreign agents operates by attacking simultaneously parts of certain tissue-cells and the correlatives of these parts in the germ-cells, then the result is what is known as parallel induction. As pointed out in our 1920 paper (p. 211) regarding the transmission of the induced eye-defects which had been secured at that time: "It is not entirely clear as to whether the result should be reckoned primarily as an example of the inheritance of a somatic modification—that is, a change produced in the lens of the uterine young which in turn has induced a change in the lens-producing constituents in the germ-cells of these young—or as simultaneous changes in the eyes and in the germ-cells of the young. In either case the inference is that there is some constitutional identity between the substance of the mature organ in question and its material antecedents in the germ." In this same paper (p. 213) it was also suggested that, since without any subsequent treatments the defects became more and more pronounced in successive generations, the degenerating eyes might themselves be "directly or indirectly originating antibodies or other chemical substances in the blood-stream of their bearer which in turn affect the germ-cells. . . . These once established, should be as effective in modifying germinal factors as corresponding antibodies introduced into the fetus through the placenta of the mother." As a further step toward rendering this possibility a probability, I would cite again the experiments which I have already reviewed, namely, the production of spermatotoxins in

a rabbit by means of its own spermatozoa, and the origination of lens-antibodies in the blood-stream through needling the lens in the eye. It is my belief that our experiments have shown that germinal constitution can be altered by immunologic influences, and that it is probable that these influences may on occasion be engendered through changes in an animal's own tissues.

University of Wisconsin.

ARE THE EFFECTS OF LONG-CONTINUED ROTATION IN RATS INHERITED?

By DR. J. A. DETLEFSEN.

(*Read April 21, 1923.*)

I have been asked to report briefly and yet critically on the present status of those unique experiments on long-continued rotation begun by the psychologists, Dr. Bentley and Dr. Griffith. Perhaps my only justification in presenting, among other data, the data accumulated largely by Dr. Griffith, lies in the fact that both Dr. Griffith and Dr. Bentley have thought important zoölogical and genetic implications were involved in their experiments, and because they have been kind enough to speak of me as coöperating in these experiments since they were housed in my laboratory, where I had ample opportunity to follow them at first hand. Furthermore, it has been possible for me to make additional observations at the Wistar Institute.

Every one is familiar with the sensation of dizziness that usually results from a rapid spinning upon one's heels, or an experience in the merry-go-round, or even with the revolving chair or turntable of the laboratory. Associated with this is a twitching back and forth of the eyes and oscillatory movements of the head to which we apply the term nystagmus. Such responses are really compensatory adjustments, the object of which is to retain the same field of vision and original bodily position which the subject had prior to the application of the stimulus. Thus in a rat rotated clockwise or to its right, say ten turns in twenty seconds, on the turntable in a horizontal plane around a vertical axis, the two eyes make coördinated movements in a direction opposite to rotation during rotation, slowly moving to the left and snapping back to normal, while the head swings to the left—*i.e.*, versus rotation. If the rotation is then suddenly arrested, the head swings to the right or in the direction of former rotation, while the eyes show the slow compensatory movement to the right with the quick return movement to the left—to which phenomenon we apply the term "after-nystagmus." This lat-

ter group of compensatory adjustments in after-nystagmus is therefore, in general, the opposite of the former adjustments of rotational nystagmus. A similar set of sequelæ, but opposite in direction, would accompany rotation to the left or counter-clockwise. All such readjustments which an animal tends to make to disturbances of equilibrium are in part dependent upon speed and duration of rotation, negative and positive acceleration, bodily condition of the animal, and finally upon the amount of rotation which the animal has previously endured. Indeed, if the stimulus is intense, the bodily manifestations may be profound and involve pronounced muscular, glandular, respiratory, and vascular responses.

This fact, that after-nystagmus persists for some seconds after rotation, makes it possible to measure the response to a given unit of stimulus in terms of time. Thus the rotation of a rat on a turntable or cyclostat, when the unit stimulus is a rate of twenty revolutions in ten seconds, produces an after-nystagmus in which the eyes oscillate for about 9.5 seconds. If the position of the rat and speed are constant, then the results of a given series of such unit stimuli applied at one time and under one set of conditions show much uniformity—varying perhaps only a second on either side of a mean. However, while the results of a series of cyclostat tests given today may be fairly uniform in themselves, they may as a whole differ from a similar uniform set of cyclostat tests administered tomorrow. Certain causes, obscure as yet (perhaps such as temperature, hunger, and excitement), may modify the averages of given sets of tests, although the results within a given set show considerable uniformity. In any event, it is of some value to be able to measure the response and know the ranges under various conditions, for large differences due to differential treatment become significant. Throughout my discussion the unit of stimulus to call forth a measurable after-nystagmus will be understood to be twenty rotations in ten seconds.

During the late war, when men were taking to the air in far greater numbers than ever before, it was necessary to gain more knowledge of the mechanics of equilibration, concerning which there was much divergence of opinion, particularly relative to a long-continued and repeated stimulus such as rotation. In an attempt to solve some of

these problems an experiment was devised for rotating white rats continuously over long periods of time. Individuals were placed in 18 circular cages, about 10 inches in diameter, revolving at speeds of 60, 90, and 120 revolutions per minute, some in a clockwise and some in a counter-clockwise direction. The animals, to be sure, made definite and pronounced attempts to adjust themselves to their new environment by running in a direction opposite to rotation and by the characteristic behavior that goes with rotational nystagmus, in the same manner that a human being does when enduring the rolling motion of a boat at the beginning of a sea voyage. Eventually they became accustomed to their novel experience and learned to eat, sleep, play, reproduce, in a word to carry out their entire life history in the rotating nest. Many animals have endured from 6 millions to 80 millions of rotations, which, put into terms of time, means two to eighteen months. Upon removal from the rotating nest, the subjects had to readjust themselves to our prosaic universe and they showed a marked after-nystagmus in much the same manner (to continue our simile) as a human being does when returning to terra firma after a long sojourn on a rolling sea vessel. The rats would often run or walk in a direction parallel to the specific former rotation for several weeks. If the random movements were counted, they bore the definite earmarks of being related to the specific previous rotation—clockwise or counter-clockwise. Two results followed:

(1) Such subjects showed increased muscular incoördination, ocular movements became modified, they declined rapidly, and died; or

(2) They recovered after several weeks and appeared normal; but after several months deep-seated effects apparently cropped to the surface, and the subjects showed modified muscular and ocular movements, the necks and heads were twisted, and signs of labyrinthine or vestibular disturbances became apparent. These disturbances were again related to the specific type of former rotation; for counter-clockwise rotation was followed by a right twist of the head and a shorter counter-clockwise after-nystagmus; while clockwise rotation gave the opposite result, a left twist with short clockwise after-nystagmus.[1] Dr. Griffith mated individuals removed from rotating

[1] Griffith, C. R., *Science*, N. S., Vol. 56, p. 676.

nests both *inter se* and to normal unrotated stock, and in the results of these matings appeared the bewildering facts which he found difficult to compromise with prevalent genetic conceptions, and which I am purporting to reinvestigate so that the facts may stand either corroborated or refuted, and in any event, at least, we hope explicable.

Briefly stated, Griffith maintains:

(1) That individuals with a long history of rotation in their ascendants showed a peculiarly high incidence of disequilibrated progeny among the descendants, although the descendants were not rotated; and

(2) That the type of disequilibration in these descendants is specific in that it shows a one-to-one correspondence to the type of ancestral rotation.

A single illustration will show the type of results which were obtained. Male 199–LR$_2$s was born in a litter of eleven rats in a counter-clockwise rotating nest on May 8. His parents had also been rotated in the same direction. Removed from the rotating nest after about two months (6.5 million rotations), he was mated to eleven normal unrotated females about the first of November. His mates were normal, because when a cyclostat test was administered they gave averages of 9.5 seconds and 9.4 seconds as the duration of after-nystagmus from counter-clockwise and clockwise rotation respectively. The unit stimulus was, as stated, 20 turns in 10 seconds. Twelve F_1 litters were born, of which five died in toto, leaving seven litters with 45 F_1 offspring. Of these 45 F_1 offspring thirty lived beyond the weaning period and 24 of these remained normal, while 6 became totally disequilibrated. While on the one hand the 24 normal F_1 individuals showed equal clockwise and counter-clockwise after-nystagmus of normal duration, the six disequilibrated F_1 individuals showed a decided twist of the head to the *right* and a concomitant reduction in after-nystagmus from a counter-clockwise unit stimulus, but a normal response from a clockwise stimulus—*i.e.*, 4 seconds and 9.2 seconds, respectively. It is noteworthy that the shorter reaction time corresponded to the type of rotation in the ascendants. Both the normal and the disequilibrated F_1 individuals were mated to give F_2 progeny. From the normal F_1, mated *inter se*, 56 normal and 4

disequilibrated F_2 were born, showing the same differential in reaction-time and twist of head which characterized these groups in the F_1. From the disequilibrated F_1, mated *inter se,* 3 normal and 7 disequilibrated F_2 offspring were derived with the same specific differences again distinguishing the two groups. Numerous other similar pedigrees could be described. Two additional facts stand out: (1) a high mortality rate throughout these experiments, and (2) frequent pathological sequelæ such as swellings and discharges from the bulla in the case of the disequilibrated subjects.

Three courses lie open to us: either to accept the implications of inheritance of acquired characters at their face value, or to admit the obscurity of a causal nexus between the observed results and the known causes, or to attempt a solution consistent with prevailing views, if possible. The last course, at least for the present, seems preferable. For this reason, I have undertaken to repeat Griffith's experiments on long-continued rotation, but with certain modifications. The facts accumulated suggest the more promising lines of future investigation. The association of pathological conditions with disequilibration raises the question whether Griffith has not merely presented us with numerous specimens of some vestibular disease or labyrinthitis. Perhaps the constant stimulation has broken down the labyrinth in part and led to a subsequent pathogenic invasion. Or possibly sheer centrifugal force has tended to drive infection from the nasal passages through one Eustachian tube and thus give the appearance of a specific unilateral disturbance completely correlated with the type of rotation. We must at least meet these suggestions and possibilities. It is even conceivable that a labyrinthitis, once established, might be passed to the progeny in two senses: (1) by direct contact, and (2) because less resistant offspring might be expected from infected parents. However, it is difficult to compromise this hypothesis with Griffith's contention of specificity. While it is easy to conceive that the direct result of rotation might well lead to a specific infection, it is nevertheless difficult to understand how specificity might be maintained in the offspring if a pathological condition is primarily all that is involved.

To obtain more light, I have sought for spontaneous cases of

TABLE I.

THE FREQUENCY DISTRIBUTION OF AFTER-NYSTAGMUS IN "MASTOID" CASES.

Position of head	Direction of rotation	Seconds of after-nystagmus															Total Tests	Mean	σ	CV
		3.5	4.5	5.5	6.5	7.5	8.5	9.5	10.5	11.5	12.5	13.5	14.5	15.5	16.5	17.5				
Head to right	Counter-clockwise	4	27	37	38	14	3										123	5.83 ±0.07	1.11 ±0.05	19.02
	Clockwise.......			1		15	14	21	16	14	10	3	4	3	3	1	105	10.50 ±0.16	2.42 ±0.11	23.03
Head to left	Counter-clockwise			3		2	7	12	24	21	13	6	6	3	1		98	11.14 ±0.14	2.09 ±0.10	18.72
	Clockwise.......	3	13	19	30	22	8	2									97	6.40 ±0.09	1.32 ±0.06	20.62

labyrinthitis or vestibular disturbance among unrotated stocks, and through the kindness of my colleagues have collected twenty-two such cases (commonly called "mastoid" cases) up to date. Twenty of these have been tested for equilibratory response. Of these, twelve showed a right twist of the head and eight a left twist. The results of 423 cyclostat tests (see Table I.) to ascertain after-nystagmus in such specimens gave the following results:

(1) Those cases showing a right twist of the head gave a much shorter response to the counter-clockwise unit stimulus; for the average (5.83 ± 0.07 seconds) is about half as long as that for the clockwise (10.50 ± 0.16 seconds).

(2) Those cases showing a left twist of the head gave a much shorter response to the clockwise unit stimulus; for the average (6.40 ± 0.09 seconds) is about half as long as that for counter-clockwise ($11.14 \pm .014$ seconds).

(3) These reactions in the cases of labyrinthine disturbance without rotation resemble Griffith's disequilibrated subjects both qualitatively and quantitatively.

The sheer distribution of reaction-times does not do entire justice to the materials; for, as stated, a series of cyclostat tests on a given day may differ by several seconds from a series taken at some other day on the same animal. Perhaps a preferable method of showing the asymmetrical nature of nystagmic response in these labyrinthine cases would be to show the differences which exist between average clockwise and counter-clockwise after-nystagmus when both sorts of tests are given under the same conditions at approximately the same time. Table II. shows the distribution of such differences. In constructing Table II., the average of each series of four to six clockwise tests on a given animal with a left twist of head was subtracted from the average of a similar series of counter-clockwise tests, when such tests were made within a few minutes of each other. This difference has always been positive in our cases up to the present time. These differences were seriated in the first row of Table II. The labyrinthine cases with a right twist of the head were similarly treated, but in this case the average for counter-clockwise tests was subtracted from the clockwise, and these differences were seriated in the second

row of Table II. The essential similarity between my pathological labyrinthine cases and Griffith's disequilibrated rats indicates that rotation had induced numerous cases of labyrinthitis in his rotated subjects.

TABLE II.

THE DIFFERENCES BETWEEN AVERAGES OF SERIES OF CLOCKWISE AND COUNTER-CLOCKWISE AFTER-NYSTAGMUS IN "MASTOID" CASES (SEE TEXT).

Position of Head	Difference (in Seconds)											Total
	1.5	2.5	3.5	4.5	5.5	6.5	7.5	8.5	9.5	10.5	11.5	
Head to right	2	4	3	3	4	3	1				1	21
Head to left	2	1	3	4	4	3	1					18

Now, while rotation may have induced a pathological condition of the labyrinth, we must confess at the outset that this simple statement does not yet satisfactorily answer all phases of the problem, for there are outstanding differences between those cases of disequilibration following rotation and my collection of "mastoid" cases. The ordinary mastoid case as I have found it in rats is an old-age condition, and the average age of rats showing this condition is well over a year. In Griffith's cases the disturbance frequently showed itself at the age of three to six months. In the colony at The Wistar Institute the mastoid case is rather uncommon, for even with rigorous search we have found only 22 cases out of about six thousand individuals. The labyrinthine disturbance which Griffith found following rotation was far more frequent than this. The severity of my mastoid cases was not as marked as in Griffith's specimens, for only one of my 22 cases showed an exudation or discharge from the bulla, while this condition was not uncommon in Griffith's cases. And finally the whole question of any specificity which would relate the nature of the disturbance in the progeny to the type of ancestral rotation still remains quite open. There are apparently some marked differences between Griffith's disequilibrated subjects and my mastoid cases, and concerning these differences we must obtain more information.

The otologists are quite agreed that constant rotation in itself does nothing after initiating the first symptoms of rotational nys-

tagmus, unless there is a centrifugal effect. In my own experiments on rotation, which began as a second and independent series on the middle of last December, I have therefore employed a different method, namely, a constant starting and stopping. All of my cages rotate at 90 r.p.m. for a minute and stop for a minute. This constant intermittent rotation has been kept up day and night, week in and week out. We have in this method the continual application of a stimulus with its compensatory response, and in addition the centrifugal action during alternate minutes of rotation. The results up to date show a gradual diminution and in some cases what appears to be a total loss of nystagmic response. Not only is there a loss of response for the specific after-nystagmus related to the specific direction of rotation, but there is a transfer such that response is modified for either clockwise or counter-clockwise stimulus. When individuals are removed from the rotating nest the effects of habituation persist for a long time, perhaps months.

It is too early as yet in my own independent series to predict whether the unrotated offspring will also show a modified response. One disequilibrated subject among those directly treated has appeared and its disequilibration corresponds to its former treatment, for it shows a right twist of the head and a shorter counter-clockwise after-nystagmus.

I am not inclined to expatiate on the insufficiencies of the Weismannian hypothesis. Weismann himself admitted these and sought to bolster up his theory by subsidiary hypotheses of doubtful tenability. The problem of the production and inheritance of adaptive response is still open and the application of experimental methods to these problems is justifiable.

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MODIFICATIONS IN THE ALBINO RAT FOLLOWING TREATMENT WITH ALCOHOL FUMES AND X-RAYS; AND THE PROBLEM OF THEIR INHERITANCE.

By FRANK BLAIR HANSON.

(*Read April 21, 1923.*)

Introduction.

The experiments described below deal with the effects of alcohol in four successive generations of treated rats, and with the effects of X-rays upon young rats treated *in utero*. The alcohol work has involved a total of 734 recorded rats, while 130 have been treated with rays.

Following the experimental results is a short discussion of the bearing of this and other recent work on the problem of the inheritance of acquired characters.

Effects of Alcohol.

Alcohol as a modifying agent of the germ cells has been employed by several workers. But the results of these various experiments, especially those of Stockard and Pearl, are by no means consistent, and much remains to be done on the alcohol problem.

Two and a half years ago I began treating the albino rat with alcohol, using the 95 per cent. commercial variety. The method of administration was by inhalation of the fumes in an airtight fume tank. This method was devised by Stockard to obviate the bad effects on digestion following the introduction of alcohol directly into the stomach. All later workers have adopted this method of treatment and are greatly indebted to Stockard thereby.

Controls.—The four generations of rats, both treated and controls, are the descendants of a single pair of inbred rats, secured from the Wistar Institute, and known there as the Tyler strain. The Tyler strain itself originated a number of years ago from a single pair of rats. All matings throughout the experiment have been

brother by sister within the litter, which means, when taken into consideration with the previous inbreeding of the Tyler strain, that the control and treated animals in this experiment are approaching homozygosity.

Treatment.—The treatment, as stated above, was by the fume-tank method. The first generation of rats was treated from the age of 16 days until they were one year and 16 days old. Their descendants of the later generations were treated only until they were 100 days of age. This covers the period of most rapid growth, and one of the objects of the experiment was the determination of the effects of alcohol upon the growth curve and the possible transmission of such effects.

Body Weight.—Careful measurements were taken every ten days of the body weight, body length, and tail length. Since there proved to be a high degree of correlation between body weight and body length, also between body weight and tail length, only the effects on body weight will be considered here.[1]

In the first treated generation no observable differences can be detected between the controls and treated animals. They are, it will be recalled, full brothers and sisters. The mean body weight, standard deviation, and coefficient of variation have been computed at ten-day intervals throughout the first year of life. The probable error of the difference between these constants is at every point in the curve greater than the difference. Hence it can not be said that the narcotic effects of the daily inhalation of alcohol fumes has had any effect upon the growth process of these animals.

The rats of the second treated generation were the offspring of the treated of the first generation, the controls of this generation the offspring of the controls of the first. Hence the two groups were first cousins, but had a common pair of rats for their grandparents. In this generation, as in the first, the differences between the groups in body weight, body length, and tail length are entirely negligible.

In the third generation the difference between treated and controls at 20 days of age, prior to the first treatment, was 6.01 times its

[1] Full tables of the constants based upon these measurements will be published at a later date.

probable error, a clearly significant difference. This wide departure of the two groups from each other was maintained throughout the period during which measurements were taken, and, indeed, increased with age, until the young adults represented a difference that was 9.89 times the probable error of the difference. The reduction in body length and tail length corresponded closely to that of body weight.

The apparent results in this generation seemed to indicate that before treatment began at 20 days there was a significantly statistical difference between the two groups, and this might reasonably be assigned to the fact of the two alcoholic generations of ancestors behind one of the groups. That the differences between treated and controls increased consistently with age until the difference reached a maximum of nearly ten times its probable error might be, and was at the time, interpreted to mean that the animals of the third generation were responding to the treatment as those of the previous generations had not done.

If the experiment had stopped here, the results would have been clear cut, with the conclusion drawn that three generations of alcoholism had had a marked effect upon body weight; and since the differences were evident before treatment of the third generation began, the inheritance effect would also have been well established.

However, the results obtained in the fourth treated generation throw some doubt upon the foregoing, for by reference to Fig. 1 it will be seen that the treated side of this generation for the first half of its growth curve is "back in the fold" with the first two generations. Later there is, as the curves show, some response to the treatment and a consequent dropping off of the curve.

The situation in the fourth generation suggests two possible explanations of the results obtained in the preceding one.

One of these is that some entirely extraneous or somatic factor was at work and produced a marked deviation from the normal. That some such environmental factor was present and responsible for the results obtained I can not categorically deny. Neither can I imagine any such factor stealing into the experiment. The conditions of housing, feeding, etc., were improved upon from time to time, but

always affected controls and treated simultaneously and equally. Part of the time treated and controls were housed in alternate cages, and at all times in identical cages, in the same room, and given the same diet. So far as known the single differential between the two

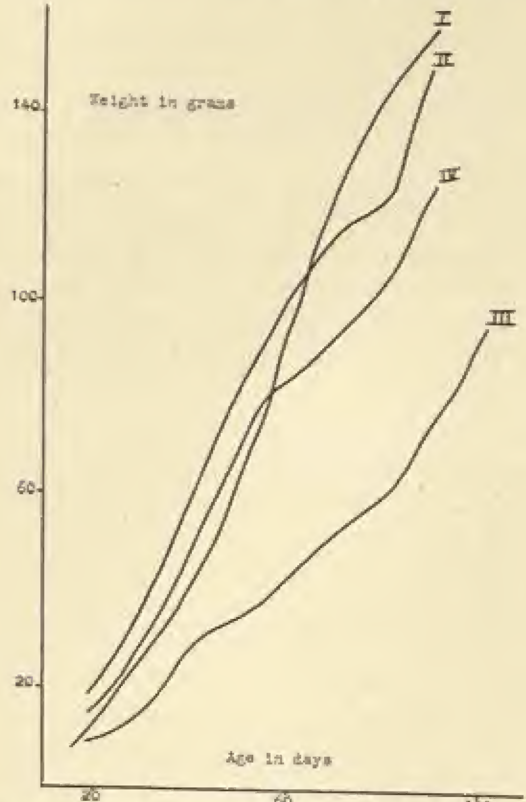

FIG. 1. Growth curves of control male rats for the first four generations of the experiment. The number at the top of each curve refers to the generation.

groups has been the alcohol treatment. However, the view that the disturbing factor in the third generation was something other than the alcohol is supported by the fact that the growth curve of the controls (Fig. 1) also drops off in the same general direction as the treated, but not to the same extent.

The other possible explanation of the return of the fourth gen-

eration is that of germinal selection. Pearl found that after alcohol treatment his fowls produced offspring which were superior to a marked degree over those produced by the controls. He accounts for this as due to the elimination or killing off of all the inferior germ cells, leaving only the superior ones to produce the next generation.

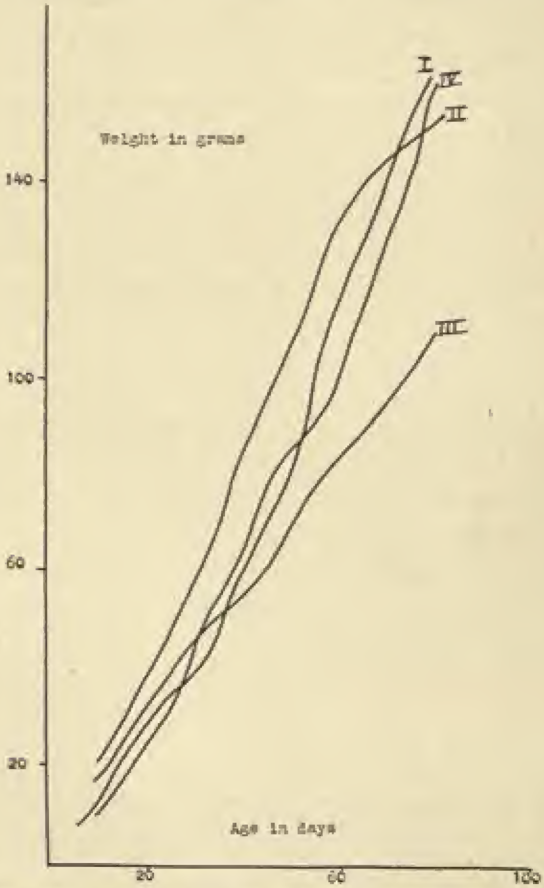

FIG. 2. Growth curves of treated male rats for the first four generations. Female growth curves approximately the same and omitted here.

That germinal selection in fowls is a fact was demonstrated by Danforth in an alcohol experiment designed especially to test this point. A germinal selection is probably also in progress in this work.

This is evidenced by the fact that while in the early generations the amount of sterility was very great, at times endangering the continuance of the experiment, in the last two generations the fertility has been completely restored, and now equals, if not surpasses, that of the controls.

Whatever the explanation of the third generation may turn out to be, it is valuable as indicating the necessity of long-continued work over a large number of generations before drawing conclusions. According to present plans at least ten successive generations of rats will be treated in this experiment.

Effects on the Sex Ratios.—Pearl and Stockard in their published statements are in disagreement as to the effects of alcohol on the sex ratio; Pearl holding that in fowls there was no effect whatever, while Stockard maintained that in guinea pigs alcohol affects the sex ratio. He accounts for the sex ratio differences by assuming that the poison has a greater affinity or is more lethal in its effect on one type of sperm than on the other.

Since the four generations of alcoholized rats showed no indications whatever of any sex ratio effect as evidenced by the probable errors of the differences, this work strongly supported Pearl's conclusions. However, since Stockard did not reduce his data to biometrical constants with their probable errors, it occurred to me to do this in order to see just how great the effect upon his sex ratios had been. Selecting six classes or groups of guinea pigs as given in Stockard's last paper, the computation of the sex ratio percentage of each was made, together with the probable error of the difference. In five of these classes the probable error was greater than the difference; in one the difference and its probable error were approximately equal; while all six classes added together showed a difference in sex ratio percentage of 1.74 ± 2.46.

The data of Stockard, Pearl, and Hanson taken together indicate strongly that severe and prolonged administration of alcohol does not have a differential effect upon male and female producing sperm.

Effects of X-rays.

The majority of the 130 rats rayed were used in preliminary experiments in determining the amount of dosage necessary to produce eye and other defects and at the same time not render the animals sterile.

Thus the minimum lethal dose, the minimum sterility dose, the defect-producing dose, and similar constants have been worked out.

Recently the dosage that would give eye defects and not at the same time render the animals incapable of producing young has been ascertained.

Eye Defects.—Several characteristic defects are produced in rats by X-rays, but in this paper only eye defects will be considered. These are the most interesting and spectacular defects, and they take several forms. In some the lenses, when dissected out, are found to be milky white. There are defects of the iris, the pupil is lacking, and again the whole eye is reduced to less than one half its normal size. One eye may be affected, the other entirely normal; both eyes may have the same defect, or each eye may show a different effect.

Why eye defects? Is it more than a curious coincidence that Guyer with lens serum, Bagg with radium, Stockard with alcohol, Duerst with naphthaline, and Little and Hanson with X-rays are able to produce the same kind of eye defects? Is the lens serum a specific for eye defects? Guyer claims that it is. And so it seems to be when considered alone. But are these other chemical and physical agents that produce like effects also specifics? Or is there an alternative explanation to specificity?

A survey of this field of work shows that a very large preponderance of all defects produced are related to the central nervous system and its sense organs. This system in the mammals is the most complex of the systems, and therefore probably the most unstable as well.

In evolution it represents the last great advance, and apparently becomes the first point of attack of any poisonous chemical (alcohol, serum), or physical agent (radium, X-rays).

Therefore, it is suggested that the simplest and most obvious explanation at the present time of the frequent appearance of brain and eye defects seems to be that these are the first of a series of defects

which appear in the presence of any one of a number of chemical or physical modifying agents.

Discussion.

The precise question involved in the term "inheritance of acquired characters" is sometimes not clearly perceived.

The definition of our problem has been stated well by Thomson: Can a structural change in the body induced by some change in use or disuse, or by a change in surrounding influence, affect the germ cells in such a specific or representative way that the offspring will through its inheritance exhibit, even in a slight degree, the modification which the parent acquired?

Lamarckism by these terms appears to be a different sort of thing from that of changes produced in the germ cells *along with* changes in the body. Alcoholism through successive generations may poison both germ cells and soma cells. This, however, is not the inheritance of an acquired character, but more properly comes under the so-called "parallel induction" effects of Weismann.

And this is the criticism commonly brought against a Lamarckian interpretation of the work with serums, alcohol, X-rays, radium, and other chemical and physical modifying agents—that the resulting changes in germinal materials may also be interpreted as due to a process of parallel induction. That is, the same physical or chemical agent acting simultaneously on somatic and germinal substances produces changes independently in each.

However, the phenomenon of parallel induction has been held by some not to be different in essence, or at least in final result, from the operation of Lamarckian factors.

Thus Castle holds that the demonstration of a permanent germinal change by environmental factors, *e.g.*, high or low temperature, while not the inheritance of an acquired character, nevertheless is an argument for evolution directly guided by the environment, which after all is the essence of Lamarckism.

If this be true, then the recent work of Guyer, Stockard, Pearl, Detlefsen, Little and Bagg, Hanson, and others, is favorable experimental evidence of the Lamarckian hypothesis.

However, if it turns out that *direct* action upon the germ cells by

various modifying agents is one thing, and somatic modifications enregistering themselves upon the germ cells is *another,* then in the experiments above referred to no light is shed on the problem of the inheritance of acquired characteristics.

In the newer work on the Endocrine system and the production of hormones we probably come nearest to the fulfillment of the Lamarckian conditions. "Deeply-saturating modifications," says Thomson, "may influence the blood and other fluids of the body, or may alter the rhythm of metabolism so that the production of internal secretions is affected, and that these internal changes in the somatic environment may act as liberating stimuli on the germ plasm and provoke variations. Prolonged exercise, *e.g.,* in dancing, may lead to an exaggerated production of muscle-forming substance; the myogenic metabolism may be enhanced; this may spread through the body. . . . It is conceivable that it might affect the germ-plasm specifically."

It also has been suggested by Cunningham, Castle, and others, that a bodily effect might be impressed upon the germ cells by hormones liberated into the blood stream by the nuclear constituents of affected body cells. And Guyer has suggested that the degenerating eyes of his rabbits are themselves, directly or indirectly, originating anti-bodies in the blood serum of their bearers—which in turn affect the germ cells. One is intrigued with the possibilities inherent in these suggestions, but it is well to remind ourselves at the same time that they are only "a conceivable interpretation of what we do not know to be a fact."

Opposed to such an interpretation are a rather large number of experiments, among them the critical experiment of Castle and Phillips on ovarian transplantation in guinea pigs. They removed the ovaries of an albino guinea pig and substituted those of a black animal. This albino female carrying the "black" ovaries was mated to an albino male and produced three litters of black offspring. It is apparent that the egg cells of these "black" ovaries had not changed in germinal constitution during the many months they were resident in the foster mother. My defective-eyed rats in the X-ray experiment did not liberate hormones into the blood stream which affected

the germ cells specifically; children and grandchildren of defective-eyed animals have all had normal eyes.

Thus it appears that after all these years Lamarck's theory is still in the "pro" and "con" stage. (This symposium itself is witness to that fact.) Results of recent work have reopened the problem and new evidence bearing upon the question of the inheritance of acquired characters has been obtained. However, it should be pointed out that this evidence is not always clear cut. It is yet insufficient in amount; and most of it is open to an alternative interpretation.

The fundamental problem of evolution is the production of the new. The cause of diversity is our distant goal. Much of the work reported here today bears on this point; and in so far as it shows environmental factors affecting germinal changes it is related to the Lamarckian theory of evolution.

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EXPERIMENTAL MODIFICATION OF THE GERM-PLASM AND ITS BEARING ON THE INHERITANCE OF ACQUIRED CHARACTERS.

By CHARLES R. STOCKARD.

During the past thirteen years a continuous experiment has been conducted in an attempt to affect the germ cells of mammals so as to definitely modify the generations to which they give rise. More than a hundred individuals have been treated and records are now available from over 5,000 animals in the several generations studied.

Pedigreed guinea pigs have been used which were originally obtained from eight different stocks. Every precaution has been taken to eliminate all differences between the control and the experimental animals except the experimental treatments.

Before beginning the treatment all individuals are mated normally in order to test their fertility and the quality of offspring. They are then treated with the fumes of commercial 95 per cent. alcohol to the point of intoxication six days per week for various lengths of time. Several have been treated as long as six years, which is actually a long life for a guinea pig. Certain of the treated animals have lived to become more than seven years old, which, so far as we know, is the longest life span recorded for guinea pigs. The fumes are inhaled while the animals are confined in a treatment tank and all ill effects on digestion, which would accompany the administration of alcohol by stomach, is thus eliminated. When alcohol is administered by stomach to these animals their digestion is disturbed and conditions arise which complicate the experiment.

The daily inhalation of alcohol fumes does not injure the health or activities or to any degree shorten the life of the treated guinea pig. The records of offspring and later descendants of such treated individuals are, however, distinctly different from the control records. Thus the alcohol affects the germ cells in some way in spite of the fact that no deleterious effect on the body or life of the treated individual is discernible.

I shall first present the data which indicate that the germ cells of these treated animals have been affected or modified by the treatment, and then consider the nature of this modification and its bearing on the problem of the inheritance of acquired characters.

If the treatments do actually affect both the male and female germ cells, then one of the simplest and clearest ways of detecting this should be by noting differences in the quality of offspring arising from alternate matings of one normal female with normal and treated males. A similar alternating experiment is made with normal males. Table I. gives such records from normal animals paired alternately with normal and alcoholic mates.

TABLE I.

Alternate Matings of Normal Animals with Normal and Alcoholic Mates.

	Matings of 35 Normal Males Alternately with		Matings of 44 Normal Females Alternately with	
	Normal Females.	Treated Females.	Normal Males.	Treated Males.
Number of Matings	81	81	77	81
Total offspring	196 2.42 av. lit.	185 2.28 av. lit.	195 2.53 av. lit.	182 2.25 av. lit.
Failure to conceive	6 7.90%	6 7.90%	3 3.89%	10 12.34%
Lived over 3 months	151 77.03%	105 56.64%	161 82.56%	118 64.83%
Died under 3 months	45 22.96%	80 43.35%	34 17.45%	64 35.16%
Defective	0	11 5.95%	0	9 4.97%

The first two columns show that when the same 35 normal male guinea pigs were mated 81 times with normal females and 81 times with alcoholic mates the records were widely divergent. The 196 young born from the normal combination showed a mortality during the first three months of less than 23 per cent. and none of these offspring were defective. (Guinea pigs are mature at about 3 months old and animals that attain this age usually survive as adults.) Of 185 young sired by the same normal fathers mated with alcoholic mothers, 56.6 per cent., or only a few more than half, lived to reach

maturity. The mortality here was about double that from normal mothers, being 43.3 per cent. as against 22.9 per cent. Eleven of these offspring, or almost 6 per cent. of them, were structurally defective, while none from the normal combination showed any such defects.

The last two columns of Table I. contain still more striking data, since these show that the male germ cell or spermatozoön is definitely affected by the treatment. In these columns we have the records from 44 normal females mated alternately with normal males and alcoholic males. The same normal mothers produced all the offspring, but those recorded in the third column were sired by normal fathers, and those in the fourth column were sired by alcoholic fathers. The 77 normal matings produced 195 young and there were only 3 failures to conceive. Eighty-one matings of the same females with alcoholic males gave only 182 young, and over 12 per cent. of these matings failed to result in conception. There was a mortality of 17.4 per cent. among the offspring of the normal matings, while the alcoholic fathers sired offspring that suffered a mortality twice as high, being 35.1 per cent. Nine of the offspring from alcoholic fathers were defective, but none from the normal sires.

This difference between the records of offspring from the same normal individuals when paired with normal and alcoholic mates clearly demonstrates an injurious action of the experimental treatments on the germ cells of these mammals. We may further analyze very briefly in the following tables the results of these effects during later generations.

In Table II. are given the records of animals occurring in the different generations of the alcoholic stock during the 10th, 11th, and 12th years of the experiment. The experiment taken as a whole has always given substantially the same results. The first column contains data from the control or normal lines. These animals are of the same blood lines as the alcoholic stock—brothers and sisters and parents and offspring are in the two groups, and actually in some cases the same individuals have first been used in the control and later in the experimental groups. There can be no doubt that any original defect or weakness that may have been in the stock from

TABLE II.

THE RECORDS OF ANIMALS OCCURRING IN THE DIFFERENT GENERATIONS OF THE ALCOHOLIC STOCK.

	Normal Stock Control.	Alcoholic Animals of all Generations.	Alcoholic Animals with Treated Parents. F_1.	Alcoholic Animals with Treated Grandparents, Great-Grandparents, etc. F_{2-3-4}.	Alcoholic Animals with Treated Great-Grandparents and Great-Great-Grandparents. F_{3-4}.	Alcoholic Animals with Treated Great-Great-Grandparents. F_4.
Total Number and Litter Sizes	1 2 3 4 5 19 114 216 132 25 Av. lit. 2.72 Av. lit. wt. 188.85 Total, 506	1 2 3 4 5 38 316 579 204 40 Av. lit. 2.50 Av. lit. wt. 170.66 Total, 1197	1 2 3 4 5 17 126 240 52 15 Av. lit. 2.56 Av. lit. wt. 165.89 Total, 450	1 2 3 4 5 41 190 339 152 25 Av. lit. 2.56 Av. lit. wt. 173.73 Total, 747	1 2 3 4 5 19 70 120 68 10 Av. lit. 2.54 Av. lit. wt. 175.88 Total, 287	1 2 3 4 5 4 16 27 12 0 Av. lit. 2.46 Av. lit. wt. 183.43 Total, 59
Lived Over Three Months	1 2 3 4 5 18 94 172 88 19 % 94.73 82.45 79.62 66.66 76 77.27%	1 2 3 4 5 45 241 364 78 11 % 77.62 76.26 62.86 38.23 27.5 61.73%	1 2 3 4 5 15 90 136 14 2 % 88.23 71.42 56.66 26.92 13.33 57.11%	1 2 3 4 5 30 151 228 64 9 % 73.17 79.47 67.25 42.10 36 69.52%	1 2 3 4 5 16 56 88 32 7 % 84.21 80 73.33 47.05 70 69.33%	1 2 3 4 5 3 15 21 12 0 % 75 93.75 77.77 100 86.45%
Total Mort. Under Three Months	1 2 3 4 5 1 20 44 44 6 % 5.26 17.54 20.37 33.33 24 22.72% = *100*	1 2 3 4 5 13 75 215 126 29 % 22.37 23.73 37.13 61.76 72.5 38.26% = N 21.22% = *180*	1 2 3 4 5 2 36 104 38 13 % 11.76 28.57 43.33 73.07 86.66 42.88% = N 21.95% = *195*	1 2 3 4 5 11 39 111 88 16 % 26.82 20.52 32.74 57.89 64 35.47% = N 21.57% = *164*	1 2 3 4 5 3 14 32 36 3 % 15.78 20 26.66 52.94 30 30.66% = N 21.87% = *140*	1 2 3 4 5 1 1 6 0 0 % 25 6.25 22.22 13.54% = N 21.21% = *64*
Prenatal Mortality	1 2 3 4 5 1 15 20 26 0 53.91%	1 2 3 4 5 9 51 137 83 22 66.23%	1 2 3 4 5 1 26 74 33 11 70.31%	1 2 3 4 5 8 25 63 60 11 63.01%	1 2 3 4 5 2 9 16 21 2 56.81%	1 2 3 4 5 1 0 3 0 0 37.50%
Postnatal Mort. Under Three Mos.	1 2 3 4 5 0 5 24 18 6 46.68%	1 2 3 4 5 4 24 78 43 7 33.77%	1 2 3 4 5 1 10 30 15 2 29.68%	1 2 3 4 5 3 14 48 28 5 30.98%	1 2 3 4 5 1 5 16 15 1 43.19%	1 2 3 4 5 0 1 4 0 0 62.50%

which the alcoholic animals were derived must also have been in the control stock, since the stocks are in all cases actually the same. All records in the present tables are of pedigree animals from thoroughly known blood lines and relationships. There is no inbreeding in either the control or alcoholic lines. It is as certain as experimental evidence of this kind can be that any differences between the records of the control and the treated groups must be attributed to the action of the alcohol treatment, since this is the only element of difference existing in the life histories or experiences of the two groups of guinea pigs.

The records for the control show that the stock is strong and well. The average litter of young is about three, and the average litter weight is 188.85 grams at birth. The data from 506 control individuals show a total mortality before reaching maturity of only 22.72 per cent. One familiar with breeding guinea pigs will recognize this as a very good record, far better than usual. In the last two lines at the bottom of the table the total mortality has been divided into pre-natal and post-natal deaths. The absorbed embryos, premature births or abortions, and stillborn young make up 53.91 per cent., or about half of the total mortality for the control column. The post-natal mortality, under three months of age, was 46 per cent. of the total. This almost equal division of pre-natal and early post-natal mortality is the normal expectation for these animals. But column 2 of the table shows that in the alcoholic generations the pre-natal is double the post-natal mortality, and among the F_1 animals in the third column the pre-natal mortality is more than two and a half times greater than the post-natal. The enormous increase of pre-natal as contrasted with post-natal mortality indicates that the less resistant germ cells of the treated animals are so injured that the zygotes arising from them succumb at a very early stage of life instead of surviving until after birth.

Table II. shows the size of litter in which the individuals occur. This is important, since animals born in large litters are at a disadvantage as compared with those born in small litters. The control section, for example, indicates that animals born in litters of two have a total mortality of only 17.5 per cent., while those born in litters of

four suffer a mortality almost twice as high, or 33.3 per cent. The average litter size in the alcoholic groups is smaller than among the control. This fact actually benefits their records and the mortality readings are corrected for the differences in litter size in the total mortality line of the table.

Considering the successive generations it is seen that the offspring from directly treated parents present the poorest record of all. Almost 43 per cent. of their young are lost before maturity, and actually 70.3 per cent. of these are either absorbed as early embryos, aborted prematurely, or are stillborn. When these F_1 animals occur in small litters their chances for survival are greatly improved, so that of those occurring two in a litter only 28.5 per cent. died, but of those in litters of four 73 per cent. died. This fact conveys an idea of the great advantage possessed by members of the small litters. These are actually partial litters, the hardy survivors of an originally larger litter. When the records of the F_1 animals are corrected for litter size their mortality is about double that of the control.

Many of these F_1 animals are defective and many are sterile; thus only the best of them are available to give rise to the following generations. Yet in spite of this partial elimination of the defectives enough effect has been produced by the alcohol treatment on some germ cells to cause the grandchildren to show an unfavorable record. When the records of the 747 animals in the fourth column are compared with the control column, the influence of the alcohol treatment is seen to be transmitted by the F_1 generation, although they had not been directly treated. The grandchildren of treated grandparents, the F_2 group, show a typical record closely comparable with that of the offspring from directly treated animals. The pre-natal mortality is here almost twice as high as the post-natal, and the total mortality is 64 per cent. greater than among the control.

Again, among the F_2 animals there are defective and sterile specimens. Thus another individual elimination and selection occurs in this generation and only the most vigorous individuals of the group are left to breed. These more vigorous specimens are in many cases mated with normal stock, so that the records of animals descended from treated great-grandparents are somewhat improved, yet the litter

size is small and the mortality record for 287 such animals is 40 per cent. higher than among the control.

Finally, the constant elimination of the defective individuals through three generations and the matings with normal stock give animals descended from alcoholized great-great-grandparents which are superior in their records to the normal control animals. They are born in smaller litters than the control, but even when this is taken into account their mortality is actually only 64 per cent. of that of the control animals. Such animals actually have a total mortality before the age of maturity of only 13.5 per cent.

The fact that the F_4 animals from alcoholic ancestry are superior in record to the control is a point of actual significance. There can be no doubt that the offspring from treated parents are decidedly inferior as compared with the control; and further, that their offspring, or the progeny from treated grandparents, are also evidently inferior, but during these generations an individual selection is taking place through the elimination from the race of the defective and sterile specimens. This selection finally brings out a group of unusually strong specimens from which all the weaklings have been eliminated, and although they are possibly not quite so productive as the control, their offspring show a record superior in vitality.

Should one desire to apply these experimental results to the human alcohol problem, it might be claimed that some such elimination of unfit individuals had benefited the races of Europe, since all of the dominant races have a definitely alcoholic history, and the excessive use of alcohol was decidedly more general three or four generations ago than it is today. That is, certain families that were alcoholic three generations ago have not been excessively so in the more recent generations.

Further evidence of significant importance regarding this selective action and the elimination of defective individuals is contained in Table III. This table was arranged to determine whether the alcoholic treatment of only male ancestors was as injurious to the offspring as the treatment of female ancestors.

The first three columns show the records of offspring from directly alcoholized parents. In the first column, when only the father

TABLE III.

EFFECTS ON THE PROGENY WHEN ONLY MALE ANCESTORS WERE TREATED OR ONLY FEMALE ANCESTORS TREATED.

	Only Father Treated.	Only Mother Treated.	Both Parents Treated.	Only Male Ancestors Treated.	Only Female Ancestors Treated.	Male and Female Ancestors Treated.
Total Number and Litter Sizes	1 2 3 4 5 9 48 87 20 5 Av. lit. 2.48 Av. lit. wt. 175.79 Total, 169	1 2 3 4 5 5 38 99 20 0 Av. lit. 2.61 Av. lit. wt. 162.82 Total, 162	1 2 3 4 5 2 22 45 12 5 Av. lit. 2.69 Av. lit. wt. 160.84 Total, 86	1 2 3 4 5 16 66 132 64 25 Av. lit. 2.66 Av. lit. wt. 175.63 Total, 303	1 2 3 4 5 8 62 114 44 0 Av. lit. 2.59 Av. lit. wt. 178.73 Total, 228	1 2 3 4 5 17 62 93 44 0 Av. lit. 2.40 Av. lit. wt. 168.84 Total, 216
Lived Over Three Months	1 2 3 4 5 9 35 61 3 2 65.08%	1 2 3 4 5 4 26 45 5 0 49.38%	1 2 3 4 5 2 15 24 6 0 54.64%	1 2 3 4 5 9 56 87 17 9 58.74%	1 2 3 4 5 7 47 90 19 0 71.48%	1 2 3 4 5 14 48 51 28 0 65.27%
Total Mort. Under Three Months	1 2 3 4 5 0 13 26 17 3 34.91% =N 20.40% =*171*	1 2 3 4 5 1 12 54 15 0 50.61% =N 20.83% =*245*	1 2 3 4 5 0 7 21 6 5 45.35% =N 21.32% =*213*	1 2 3 4 5 7 10 46 47 16 41.25% =N 21.09% =*188*	1 2 3 4 5 1 15 24 25 0 28.37% =N 21.50% =*132*	1 2 3 4 5 3 14 42 16 0 34.72% =N 21.01% =*165*
Prenatal Mortality	1 2 3 4 5 0 9 20 9 3 69.49%	1 2 3 4 5 1 9 38 11 0 71.95%	1 2 3 4 5 0 5 15 3 2 66.66%	1 2 3 4 5 4 8 26 37 11 68.80%	1 2 3 4 5 1 6 14 14 0 53.84%	1 2 3 4 5 3 11 23 9 0 61.33%
Postnatal Mort. Under Three Mos.	1 2 3 4 5 0 4 6 8 0 30.50%	1 2 3 4 5 0 3 16 4 0 28.04%	1 2 3 4 5 0 2 6 3 2 33.33%	1 2 3 4 5 3 2 19 10 5 31.20%	1 2 3 4 5 0 9 10 11 0 46.15%	1 2 3 4 5 0 3 19 7 0 38.66%

was treated, the average litter was small, the total mortality was 71 per cent. higher than normal, and the pre-natal deaths were almost two and one third times greater than the early post-natal mortality. The entire reaction is typical of the alcoholic line.

In the second column, where only the mothers were treated, the records are considerably worse than the records from the treated fathers. The average size of the litters was somewhat larger than from the treated males, but the actual litter weight of these larger litters was less. The individuals from alcoholic mothers were small at birth. The mortality among these offspring was 50.61 per cent., or almost two and a half times higher than among the control. For comparison, if we call the mortality of control animals 100, then the mortality of the offspring from treated fathers is 171, and from treated mothers 243.

The third column shows that the treatment of both parents does not greatly alter the results which would have followed if the mother alone had been treated. The total mortality is actually a little lower, but this is probably due to the small number of individuals recorded in this column.

The last three columns give the records of 747 descendants of the survivors from the first three columns. These records indicate the degree of transmission of the induced defective conditions. They supply the most striking data pertaining to the selective action which took place in the first filial generation of the alcoholic race to eliminate the defective individuals.

The records show the mortality to be highest among animals descended from treated males. And among such animals the pre-natal mortality is more than twice as great as the early post-natal mortality.

Animals having only female ancestors that had been subjected to alcohol treatment show in the fifth column a lower mortality than those from treated male ancestors. Here the pre-natal and post-natal mortalities are almost equal. At first sight it would seem as though the treatments had acted more severely on the male than on the female germ cells. None of the animals in the last three columns are the offspring of directly treated parents, so that all inferiority must be

attributed to the action of the treatment on the ancestral germ cells. The superior record in the female treated column is, however, no doubt due to the more rigorous elimination of defectives that occurred among the F_1 animals in column two.

The last column shows that the group of animals recorded as descended from both treated male and female ancestors have also a bad record as compared with the control data shown in Table II. The results in this column are at first sight somewhat misleading, since they are better than those from only male ancestors treated and are worse than those from only female ancestors treated. But here again the elimination which took place in the first generation has ensured to some extent the quality of the survivors, and makes it improper to compare the partial results as an actual measure of the original effect induced.

We may briefly compare the data in the two sets of columns to demonstrate the consequence of the severe elimination of affected individuals which is taking place in these experiments. In the first three columns the size of the litter was smallest from treated fathers, larger from treated mothers, and largest when both parents were treated. In the last three columns the litter size is exactly reversed; it is largest for those with male ancestors treated, smaller when female ancestors were treated, and smallest among animals with male and female ancestors treated. The mortality records show about the same relationship. Among the offspring of directly treated parents the mortality was lowest from treated fathers—171 against 100 as normal; the mortality was very high from treated mothers—243 against the normal 100; and high when both parents were treated—213. The descendants from the treated males which had suffered the lowest mortality in the first generation subsequently show the highest mortality in later generations—188 against 132 for descendants of treated females, and 165 for the descendants from both treated males and females. This simply means that when the action of the treatment is severe on the first generation, as was the case when the mothers were treated and the highest mortality among offspring obtained, only the comparatively hardy individuals survive. Their descendants later show a superior record in comparison with the descendants from

treated males among which the eliminations in the first generation had not been so severe. Taking the mortality records of the first three columns and writing under them the records from the same lines in the last three columns, we find that when the mortality is high in the first generation it is low for subsequent generations, and vice versa:

171	243	213
188	132	165
359	375	378

If the two numbers in the three sets of mortalities be added together, the sum in each case is about the same.

When we consider the welfare of the race or stock rather than that of the individual it is found that the descendants of those groups of animals which suffered the highest mortalities and thus withstood the most rigorous elimination are superior in quality to the descendants from the groups less severely affected. This individual selection furnishes a great advantage to the later generations, as is shown by the superior quality of the F_4 group of guinea pigs in the Table II.

From the standpoint of genetics, just how are such results to be interpreted? They certainly show that the germ cells of the treated guinea pigs were injured or changed. And this change in the germ cells gave rise to generations of individuals inferior in quality to the control. But also after several generations the individuals of these treated lines actually become superior to the control. This can only mean one of two things. Either, in the first place, the treatment only injured a portion of the germ cell population and was not severe enough to injure the most resistant germ cells, so that each generation of progeny are derived from a mixture of injured and uninjured cells. The uninjured ones were actually the best or most resistant germ cells of the original group. The second possibility is that the less resistant members of the germ cell population are injured and give rise to the inferior individuals of subsequent generations, while other germ cells are actually stimulated or benefited by the treatment, and these give rise to superior individuals. In any case the injured individuals are eliminated after several generations and the superior uninjured group remains.

It is also important from the genetic standpoint to consider the nature of the modifications which have been produced in the progeny by the treatment of the parental germ plasm. No one new character or mutation has been brought about and no single old character has fallen out. The treatment has not shown, so far as has been de-

Fig. 1. A uterus opened to show a normally developing fœtus along with a small defective embryo which is being absorbed.

tected, a specific action on any given gene within the chromatin of the germ cells. The action has been general, affecting more the constitution of the hereditary material as a whole and producing a subnormal condition which has lowered the quality of development and brought about slow arrested individuals.

The defects and arrested conditions shown by the progeny of

alcoholic guinea pigs are closely similar in kind to those produced in birds and lower vertebrates by directly modifying the rate of development of the egg. It seems as though the alcohol treatment had affected the chromatin of the germ cells in the guinea pigs so as to

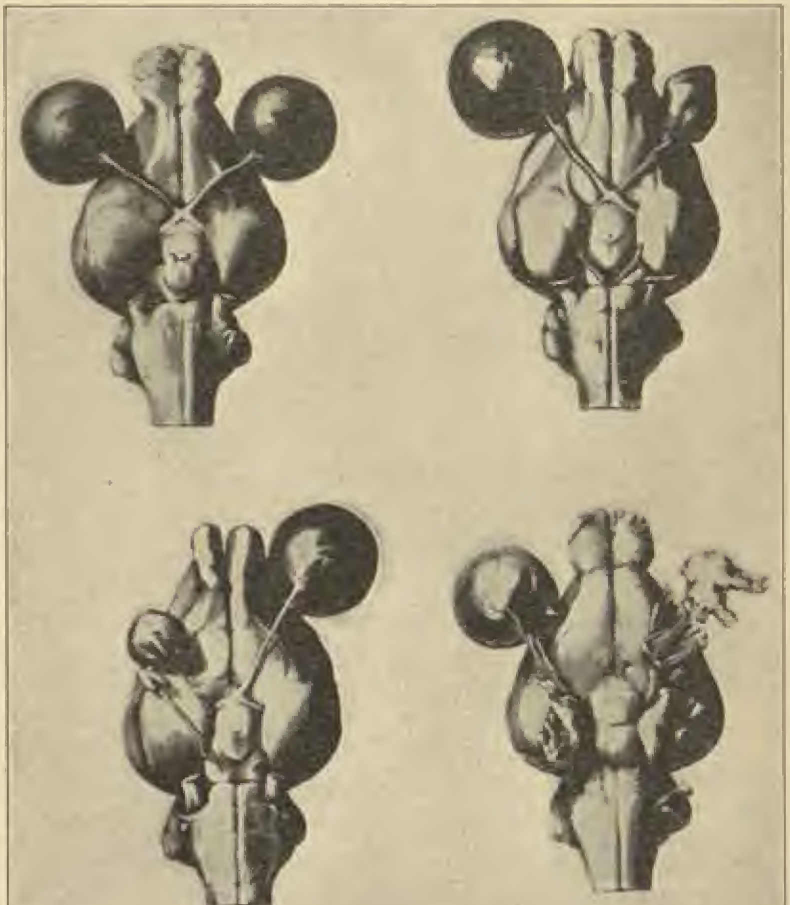

FIG. 2. Ventral views of the brains from guinea pigs of the alcoholic lines showing various conditions of maldeveloped eyes.

render it incapable of giving rise to a normal zygote with a vigorous rate of development. There occur numerous defects of the central nervous system and the eyes are very commonly affected. Specimens occur with no eyes at all or with all degrees of defective eyes on

either one or both sides. Exactly the same eye conditions, involving either the retina or crystalline lens or both, are readily produced in other vertebrate embryos by the use of either physical or chemical agents which tend to alter the normal rate of development. Any modification in the rate of development due to unfavorable conditions is usually indicated by some structural defect of the eye.

The eye conditions which Guyer has obtained by the treatment of rabbits with highly toxic lens antigens may be similar to the above eye reactions. If the reaction to the lens substances was specific, both lenses of the embryo should be affected and not only one as is often the case, and the degeneracy of the eye ball and retina would not be expected.

I am inclined to believe that any toxic stuff properly administered to the mammalian body may act upon the germ cells and injure them in a general way so that they may subsequently give rise to a low grade or arrested development and therefore to a defective individual. Such a general effect on the germ cell is *a priori* what would be expected rather than that a particular substance should be so specific in its action as to select one or a few of the genes in any single chromosome. One should think that quite a highly refined method would be necessary to selectively injure or affect an individual factor or gene.

From the above results and considerations it is probably evident to the reader that these experiments do not furnish evidence of the inheritance of acquired characters. The alcohol treatments used do not injure or noticeably modify the structure or behavior of the treated animals. The weak and defective offspring and later descendants of alcoholic guinea pigs have no "new character" that was acquired by the parent as a result of the treatment. But while the parents lived long and well, their descendants showed a high early mortality and were structurally defective in many cases.

On the other hand, these experiments seem to make it more difficult to imagine how a character acquired during the life of the parent could act on the germ cells in so specific a way as to cause them to develop zygotes exhibiting this exact acquired modification. These experiments do show that the germ cells may be modified by a treatment administered to the parent, and these results have been con-

firmed by similar experiments on other animals, notably by Pearl with fowls and MacDowell with rats, but in none of the experiments is the exact condition attained by the treated parent transmitted to the progeny. While the treated animals have not been injured, or may have been benefited, their early descendants are often rendered less capable of survival and are frequently defective.

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INFRA-RED SPECTRA.

By H. M. RANDALL.

Work in the infra-red region, as in other portions of the radiation spectrum, is subdivided, the different fields being characterized by the purposes sought by the workers in these fields. This work is primarily concerned with the near infra-red region, 1 to 7 μ, and the underlying idea is to develop experimental methods which will permit the measurement of infra-red line and band spectra with such accuracy and completeness that the results may become integral parts of general spectroscopic data.

The methods used in obtaining the emission spectra of elements are substantially those first used by Lewis [1] and later developed by Paschen.[2] Characteristic radiations of substances are obtained from discharge tubes in the cases of gases and for solids from arcs into which the materials, metals or salts, are introduced, by placing them in the positive carbons in holes of suitable size. The advance made by Lewis and Paschen consisted primarily in the use of gratings to analyze this radiation, the spectra produced being passed over a linear thermopile by rotating the grating. The presence of lines was evidenced by deflections of a galvanometer in series with the thermopile. The high dispersion obtainable from gratings so attenuates the continuous spectrum upon which the line spectra are superposed that it is the source of very little trouble, while the lines are given the maximum separation and therefore become more completely measurable. These two advantages are somewhat at the expense of the completeness of the results, since the detection and measurement of weak lines require the conservation of the energy to the greatest possible extent, while a grating through its production of multiple spectra dissipates this energy. Through improvements in the component parts of the detecting and registering systems, and particularly [3] by increasing the intensity of the emitting sources of radiation, very material gains

[1] Lewis, *Astrophysical Journal*, 2, pp. 1 and 106, 1895.

[2] Paschen, *Ann. der Physik*, 27, p. 537, 1908; 29, p. 625. 1909.

[3] Randall, *Astrophysical Journal*, 42, 195, 1915.

have been possible on the side of completeness. Thus, in a redetermination of the line spectra of Sr., now approaching completion, in the region between 10,000 and 30,000 A., lines whose intensity in terms of galvanometer deflections were in the first determination 10 mm. are now 250 mm. This increase in energy has resulted in increasing the number of lines in this region by four or five fold. The thermopile will, however, always be at a great disadvantage when compared to the photographic plate as a means of detecting faint radiation, since it is not an integrating device. The accuracy obtainable in these measurements justifies expressing the wave-lengths in numbers of five or six significant figures. This accuracy makes it possible to use these data in a determinative manner in common with that of the photographic regions. It serves to complete, therefore, the total emission spectrum extending from the extreme ultra-violet through the visible into the infra-red and accordingly plays much the same part as the other portions of the spectrum in solving those problems for which spectroscopic data are particularly fitted. As these are well known, the major portion of this paper will concern itself with the more recent development of methods of determining the fine structure of the absorption bands of gases and the contributions which these data make to the important problems of atomic and molecular structure.

The writer's interest in absorption spectra began with the publication of the results of von Bahr [4] on the infra-red absorption bands of narrow bands was accounted for by the hypothesis that quantum effects were to be attributed to molecular rotations as well as to vibrations, the original Planck idea. Such effects had been used previously by Nernst to account for the temperature variation of the atomic heats of gases. The optical methods, however, promised to give more direct and definite data upon molecular and atomic structure provided the bands could be quite completely resolved into their fine structure and these narrow lines measured with an accuracy comparable with that obtained for emission spectra in the same region. The experimental method which was adopted at this time has been used extensively. While the particular form the apparatus assumes varies somewhat with the available equipment, probably the most

[4] von Bahr, *Verh. d. D. phys. Ges.*, 15, p. 1153, 1913.

satisfactory from the point of view of compactness is that which was adopted for the first work, that of Sleator[5] in a study of the structure of the bands of water vapor. Reference to Fig. 1 shows this

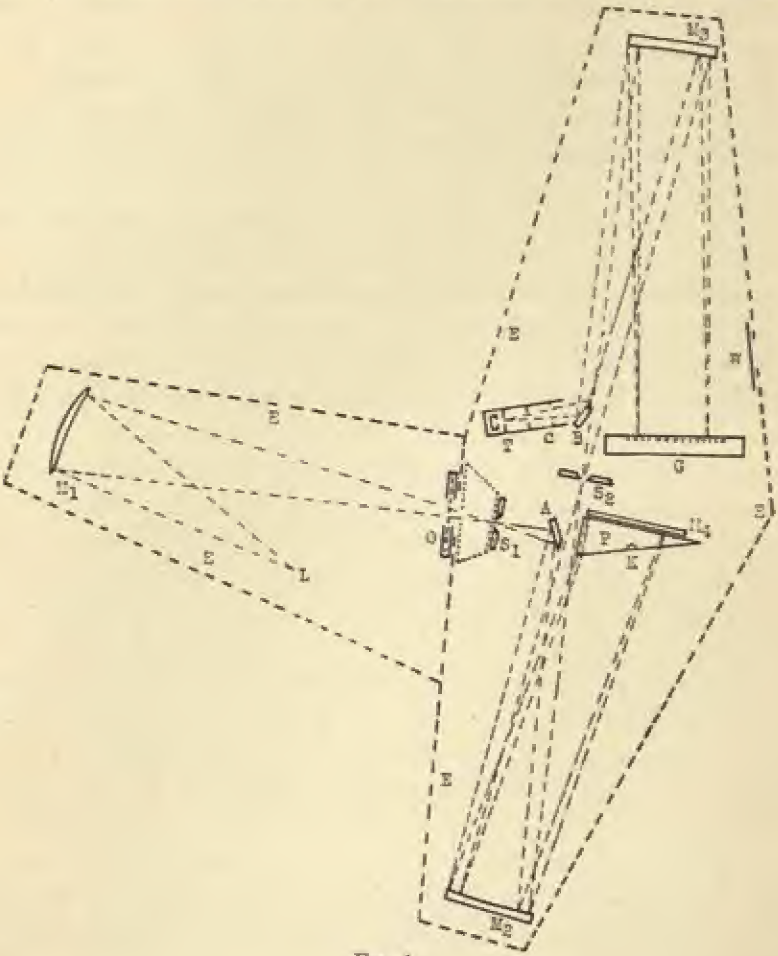

Fig. 1.

arrangement. Complete radiation from a Nernst filament L is passed through an absorbing chamber which is generally located between M_1 and S_1 and the emergent radiation examined spectroscopically by the double spectrometer, a grating spectrometer $S_2M_2GM_3BT$ pre-

[5] Sleator, *Astrophysical Journal*, 48, 125, 1918.

ceded by a prism spectrometer $S_1AM_2PM_4M_2S_2$. The function of the prism spectrometer is to present to the slit of the grating spectrometer, S_2, that portion only of the spectrum which is under examination, thus preventing overlapping spectra of higher orders. The small angle of the prism, P, produces only such dispersion as is necessary to prevent this overlapping. Thus if the region at 3.4 μ is under examination, the prism is rotated till a portion of this region is upon the slit S_2. When this has been analyzed by the grating spectrometer a slight rotation of P presents a further portion of the region for examination. Gratings of different constants are employed to give maximum resolution for the particular band under examination. Thus gratings having 20,000 lines per inch are used upon bands lying below 2 μ. This gives a spectral range of about 9 Å. upon the thermopile slit. For bands below 3 μ a grating having 15,000 lines per inch can be used. This gives a spectral range upon the thermopile slit of about 15 Å. units. Bands lying at longer wavelengths require coarser gratings with a resulting greater spectral range upon the thermopile slit. Barker has ruled several echelette gratings which are very successful in conserving the energy in the regions of the bands investigated. They have contributed materially to the progress of the work.

The effectiveness of this method which uses the maximum resolutions which a series of graded gratings can give will be evidenced by the results which follow.

Fig. 2 gives a fairly complete historical development of the HCl band at 3.4 μ and shows the manner in which the structure of the band appears when the spectral range covering the slit is decreased by decreasing the slit width and increasing the dispersion of the optical systems used. Angström and Palmer[6] with a spectral range of 4,000 Å. upon the slit recorded the band as a single broad band, while Burmeister[7] with one tenth this spectral range upon the slit resolved the band into a doublet. Von Bahr by decreasing this range to 100 Å. showed unmistakably the fine structure of each component of the doublet. A further decrease to 70 Å. (approx.) resulted in the very evident resolution obtained by Brinsmade and Kemble.[8]

[6] Angström and Palmer, *Ofv. af Kongl. Vet.-Akad. Fork*, p. 389, 1893.

[7] Burmeister, *Verh. d. D. phys. Ges.*, 15, p. 589, 1913.

[8] Brinsmade and Kemble, *Proc. Nat. Acad. Sci.*, 3, p. 420, 1917.

All of the results so far were obtained with prism spectrometers. Imes in his thesis [9] on the fine structure of the bands of the halogen acids, following Sleator's work on water vapor, first used the double spectrometer in the study of this HCl band. With a grating having 7,500 lines per inch the spectral width of the thermopile slit was reduced to 29 Å. The lines were again more definitely resolved and the first evidences of a faint series found between the lines at the

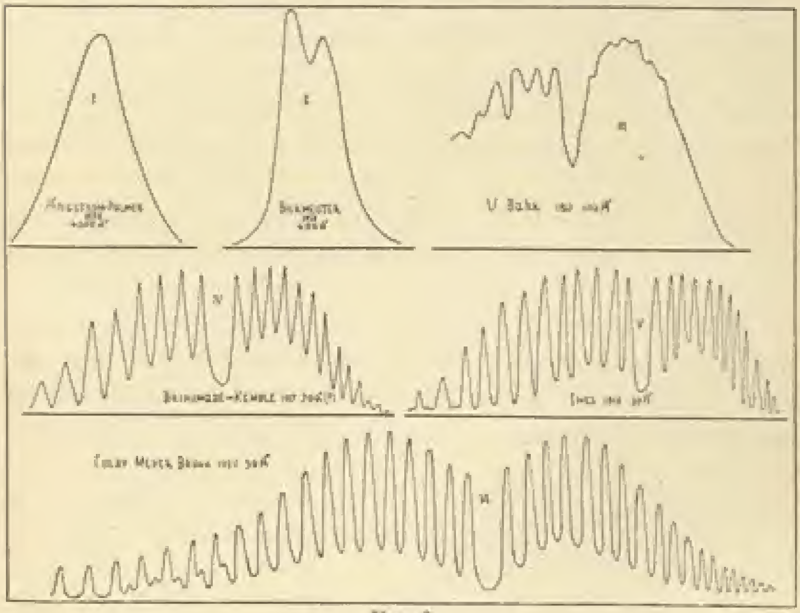

FIG. 2.

extreme left. Colby, Meyer and Bronk,[10] using the same method and dispersion, but heating the absorbing gas till the chamber walls were at a low red heat, extended the number of observable lines at both ends till a total of 39 lines altogether had been measured. In this last work a new series is unmistakably shown by five faint lines at the left.

[9] Randall and Imes, *Proc. Amer. Phys. Soc.*, Nov., 1919. Imes, *Astrophysical Journal*, 50, 251, 1919.

[10] Colby, Meyer and Bronk, *Astrophysical Journal*, 57, p. 7, 1923. Colby and Meyer, *Astrophysical Journal*, 53, p. 300, 1921. Randall, Colby and Paton, *Phys. Rev.*, p. 541, 1920.

The advantages of the method are not only in the greater resolution resulting from the high dispersion obtainable from gratings, but also in a corresponding increase in the accuracy of measurement of the wave-lengths of the individual lines. The results of Imes and of Colby, Meyer and Bronk are accurate to the fifth significant figure. The positions of these lines can be expressed with great exactness by the following formula: $\nu = 28860.7 + 205.9831n - 3.01022n^2 - 0.02056583n^3$. The differences between the values of the wave-lengths computed by this formula and those directly observed is, on the average, about 2Å. units.

While the researches thus briefly outlined have been primarily experimental, they have all been undertaken on account of the promise they offered of giving very definite and exact information of the structure of the molecular systems taking part in the absorption. Accordingly a brief account of the theoretical results directly founded upon the data of these researches or confirmed by them will be in place. Band spectra are now quite generally attributed to the molecules of the radiating or absorbing gas. The great success of the Bohr atom in accounting for line spectra requires the application of the same ideas to molecular radiation. Accordingly the molecules are supposed to exist in a number of stationary states during which they neither absorb or radiate energy. When there is a transition from one stationary state to another the radiation, emitted or absorbed, has a frequency proportional to the amount of energy liberated or absorbed during the transition—that is, $W_1 - W_0 = h\nu$. In the case of molecules three kinds of transitions are possible, one electronic and two atomic. The electronic transition occurs in the molecule as in the atom when an electron shifts from one of its possible orbits to another.

The two types of atomic transitions are due to the fact that the molecule may store energy both by the vibrations which may exist between its component atoms and by its rotation about one or more axes. For the molecule to exist in a series of stationary states, therefore, it is necessary to assume not only that the electrons must be limited to certain permissible orbits, but that only certain amplitudes of vibration and certain states of rotation are permissible.

Transitions may occur in any one of these three components which determine the stationary states of the molecule, in any two of them simultaneously, or in all three. Of the three transitions, the electronic transitions would involve the greatest energy changes, the changes in vibrational states the next, and the changes in rotational states the least. Transitions involving large energy changes might carry with them transitions of one or more of the other kinds involving smaller energy changes. Thus electronic transitions might be accompanied by both vibrational and rotational transitions, while vibrational transitions might be accompanied by rotational. If simultaneous transitions occurred, they would not necessarily be all in the same direction; certain transitions could release energy while others were absorbing energy. Molecules in different stationary states may to a certain extent be regarded as different molecules, since the physical constants which define the molecule vary from state to state. This would result in the energy changes accompanying any particular transition being different in amount in molecules which were in different states with respect to the other two possible transitions. Thus the same electronic transition releases slightly different amounts of energy depending upon the particular vibrational and rotational states in which the molecule finds itself at the time of the electronic transition. These coupling effects are useful in accounting for some of the characteristics of the band spectra. It is evident that these three types of transitions offer, through their possible combinations together with the coupling effects, great opportunities for explaining even so complicated spectra as band spectra.

The bands found in the photographic regions, the ultra-violet and visible, have been very fully accounted for in some cases as resulting from all three transitions occurring simultaneously. The bands in the near infra-red, however, appear to be due to the two atomic transitions alone. The situation here is accordingly somewhat simpler, and if these bands can be quite completely resolved and accurately measured, their study presents decided advantages. It will best serve the purpose of this paper to use as illustration those spectra which show the characteristic properties of these bands most perfectly. Such are the spectra of the Halogen hydrides and methane.

Of these the bands of HCl gas have been most completely analyzed. These bands are shown in Fig. 3, the narrow components being replaced by straight lines for convenience, the length of the lines indicating roughly the intensities. In both these systems the following characteristics are evident: (*a*) There is a region in the midst of the band in which a line is wanting. (*b*) The lines may be grouped in pairs about this region as ± 1, ± 2, etc. (*c*) The lines are very regularly spaced, but lie more closely together as the short

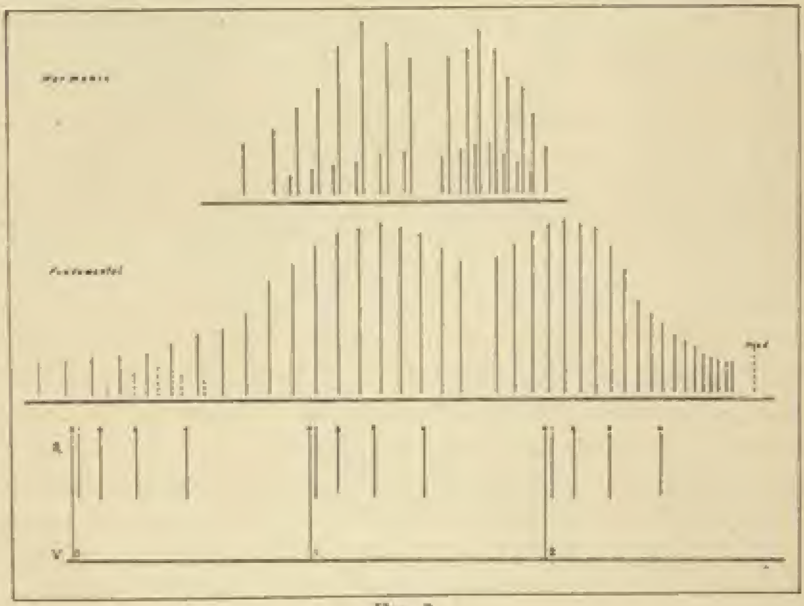

FIG. 3.

wave-length of this band is approached. (*d*) In the "Fundamental" there is a faint series shown by dotted lines in the long wave-length end of the band. (*e*) In the "Harmonic" there is a faint series superposed upon a strong series. (*f*) The number of lines on each side of the mid-region is increased by increasing the temperature of the gas.

This paper will attempt to show in a qualitative way only how these characteristics may be accounted for by using ideas developed largely to account for the characteristics of atomic radiation as shown by line spectra. As the near infra-red bands are supposed to be due

to the two types of atomic transition only, it will not be necessary to take account of electronic transitions.

The two atoms of the HCl molecule vibrate with respect to each other along the line connecting them. The Sommerfeld formulation of the quantum hypothesis states that $\int pdq = nh$ where p is the impulse coördinate and q the space coördinate. In the case of vibrational energy this leads to expressions for E_n, n being any positive integer.

These quantities are represented graphically by the long lines, V, in the lower part of Fig. 3. The line with the subscript, 0, represents the vibrational state, zero. The molecules in this state are not vibrating. The line with subscript 1 represents the vibrational state 1 where the atoms vibrate with the smallest of the permissible amplitudes and possess the minimum amount of vibrational energy, etc.

The molecules rotate about axes through their centers of mass normal to the lines connecting the atoms as will be shown later. Sommerfeld's formulation $\int pdq = mh$ leads to the expression

$$E_m = m^2 \frac{h^2}{8\pi^2 I}$$

for the permissible energies of rotation, m being any positive integer and I the moment of inertia of the molecule about its axis of rotation. The energies associated with each of these permitted states of rotation may be represented in a way similar to that used for the vibrational states. Since the energy involved in rotational transitions is small in comparison with that of the vibrational transitions, the lines representing the rotational states are much closer together, in fact can not be represented on the same scale as the other type of transitions if the positions are to be separated. Moreover, the permitted rotational states call for energies which vary as the square of the number of their state or m^2. Since the molecule may rotate in any of its possible modes of rotation when vibrating in any of its possible vibrational states, these rotational energy levels are associated with each vibrational level. In the figure they are shown by the short lines, R, at the top. These energy levels represent every possible state of the HCl molecule, and all the absorption lines, as well

as the characteristics of their grouping, are to be accounted for by transitions between these states.

Limitations similar to those imposed upon transitions between stationary states in atoms are to be imposed upon the transitions which can occur between the molecular stationary states. All possible vibrational changes are found to occur which indicates that the vibrations of the atoms in the HCl molecule are not S.H.M. Only those rotational changes occur which step the rotational state up or down one level from the original rotational state. (This is Bohr's correspondence principle applied to molecular radiation.) There are a number of reasons for supposing that HCl gas in its normal condition has no vibrational energy—that is, its molecules are all in the 0 state vibrationally. They may, however, be in any rotational state. Accordingly the first group of levels represents the normal state of HCl gas, where the possible rotational states should not be limited to 4, but should run on to much higher numbers; 20 have been observed.

When complete radiation is passed through a column of HCl gas certain molecules absorb radiation and pass out of their initial stationary states, represented by various levels of the first group into levels of some higher group, subject to the limitation that the rotational level may go up or down one step only. When the energy absorbed changes the molecule from one R level to another R level in the V_0 group the Bohr relation $W_1 - W_0 = hV$ gives as the absorbed radiation frequencies in the far infra-red region, since $W_1 - W_0$ is a small quantity. Such transitions result in the rotation spectra of Rubens.

On the other hand, all those molecules in vibrational state 0 and rotational state 1 which absorb enough energy to lift them to the group associated with vibrational state 1 will move up 1 rotational state to state 2 or down 1 rotational state to state 0. If these rotational transitions be assumed equally probable, then equal numbers of molecules will have passed from a common initial state to two final states, differing by the small amount of energy corresponding to a change from 0 state rotationally to state 2. Since here there have been two slightly different energy changes involving equal numbers of molecules, there will be radiation of two slightly different fre-

quencies absorbed; these are taken to represent the first absorption lines ± 1 on each side of the center of the band. In a similar way some of the molecules in state 0 vibrationally and state 2 rotationally will absorb energy and pass to state 1 vibrationally and to either state 3 or 1 rotationally, giving rise to the second lines ± 2 to the right and left of the center. Thus all of the lines of the band at 3.4 μ may be accounted for. As there are 20 such pairs observed, there must have been molecules in such numbers in the 0 state vibrationally and 20 rotational states in the normal gas as to give measurable results.

Should some of the molecules in the normal condition absorb sufficient energy to pass to state 2 vibrationally, there would be a second band composed of pairs of lines situated in a similar manner about a center. Since the frequency of the radiation is proportional to the energy involved in the transition and the energy absorbed for a transition to state 2 vibrationally is about double that to state 1, the frequency of this second band system will be about double that of the first. This is the "Harmonic" shown above.

In measuring this band Imes used a grating with 20,000 lines per inch, which gave a spectral range on the thermopile slit of 9 Å. As the diagram of this band shows, each line appears as a doublet. The interpretation is that the Cl atom is isotopic.

The vibrational energy is a function of the masses of the vibrating atoms. The computed differences of the frequencies of the lines due to Cl atoms of atomic weights 35 and 37 agree with the differences between the observed lines within experimental error. As this method of detecting isotopes differs entirely from the positive ray method of Thomson and Aston, it is highly desirable to develop it further. As the separation between adjacent lines of a band varies inversely as the moment of inertia of the rotating molecule, it is evident that favorable results may be hoped for in those cases only where the isotopic atom forms a molecule of small moment of inertia with some light atom, preferably hydrogen. As there are several isotopic atoms which unite with hydrogen under proper conditions of pressure and temperature, this problem presents interesting possibilities.

When HCl gas is heated 600 or 700 degrees apparently the mole-

cular energy is increased sufficiently to have a considerable number of molecules in state 1 vibrationally. With the passage of radiation some of these molecules absorb enough energy to pass to state 2 vibrationally and there will be a band system of the same order of frequencies as the first, since the energy of transition from state 1 to state 2 is nearly the same as from 0 to 1. This system is weak, since the number of molecules involved is relatively small. It is represented by the five dotted lines in the left end of the fundamental.

A second effect of high temperature is to increase the number of molecules having relatively large energies of rotation. There is accordingly an increased intensity of the lines due to transitions between states involving relatively large rotational energies. This is sufficient to permit the extension of Imes original 12 pairs to the 20 pairs of Colby and Meyer.

The crowding of the lines as the short wave-length end of the band is approached has its explanation in the coupling which exists between the vibrational and rotational states. The molecular constants differ slightly with the particular states of vibration and rotation. The energy absorbed in the transition between the vibrational states 0 to 1 is progressively less, as the accompanying rotational transitions are those between the states of higher energy content which are characterized by the larger values of m. Thus less energy is required to change the molecule from vibrational state 0 to state 1 when the molecule is in rotational state 5 initially than if it is in rotational state 4 initially. This means that the pair of lines resulting when 5 is the initial rotational state is displaced slightly to the long wave-length side of the band with respect to the pair resulting when 4 is the initial rotational state. Were this effect not present the pairs would all be symmetrically situated about the central region of the band. As it is, the effect increases progressively with increase in m, and there is a very distinct tendency of the lines to come to a head on the short wave-length side of the band.

The central region of double the spacing between adjacent lines could contain the line due to the vibrational transition 0 to 1 combined with the rotational transition 0 to 1. Its absence is ascribed to the fact that the 0 rotational state does not exist, or if it does its

time of duration is too short to be productive of absorption. There are reasons why this point of view is not satisfactory.

The band at 3.3μ due to methane[11] is shown in Fig. 4. It contains 20 pairs and is similar in its characteristics to the HCl fundamental except at the central region. With methane this region is an absorption region instead of a region of high transmission as in HCl. The assumption made to account for this absorption is that the atomic vibrations within the molecule have components parallel to the axis of rotation. This permits vibrational transitions without accompanying rotational transitions. There is an absorption line, therefore, due to the vibrational transition 0 to 1 alone. Due to the coupling effect, however, the energy change involved in this transition varies slightly with the rotational state of the molecule. There is a line of this kind, therefore, for every group of molecules in the various stationary rotational states. As the properties of the molecule change but little

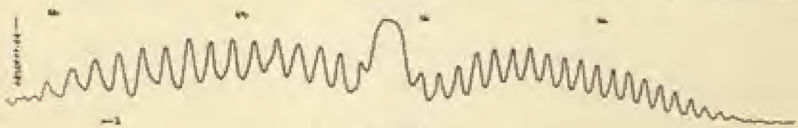

FIG. 4.

as the molecule assumes different rotational states, these lines have nearly the same frequencies and are not resolved. On this basis the axis of rotation of the HCl molecule is normal to the line of vibrations.

Methane, unlike HCl, may have more than one characteristic vibration frequency. Coblentz found bands at 7.7μ, 3.3μ, and 2.4μ. Cooley has also determined the fine structure of the band at 7.7μ and finds that it has the characteristics of the band at 3.3μ. There are thus apparently two characteristic frequencies of vibration in the methane molecule. There should therefore be an energy diagram for the methane molecule containing two sets of energy levels, each similar to that of HCl in Fig. 3. These two sets of energy levels are somewhat analogous to the sets of energy levels of atoms characteristic of the different series. Combinations involving transitions between levels of the two sets may therefore be expected. The fine

[11] Cooley, *Phys. Rev.*, No. 3, Vol. 21, p. 376.

structure of the band at 2.4 μ is quite different from that of the bands at 3.3 μ and 7.7 μ, and its most prominent lines appear to be accounted for by such combinations between the two sets of energy levels.

Half quantum numbers designating stationary rotational states of molecules are being used in discussions of band spectra. If it is considered that the electronic rotations within molecules possess a molecule which is quanticized is the angular momentum of the entire molecule resulting from both electronic and atomic rotations, it is evident that fractional quantum numbers to designate the stationary states of molecular rotations as distinguished from electronic rotations are necessary. For the lowest steady state it seems necessary to assign to the vector sum of the angular momenta of the various electronic rotations a magnitude of a $\frac{1}{2}$ quantum and to the nuclear rotations a $\frac{1}{2}$ quantum. Transitions occurring between stationary states of molecular rotation are always integral, so that these states are designated by the quantum numbers $\frac{1}{2}$, $\frac{3}{2}$, $\frac{5}{2}$, etc.

Work in infra-red bands contributes experimental evidence in favor of this conception. The two lines on either side of the central region, +1 and —1, result from the vibrational transitions 0 to 1 combined with the rotational transitions 1 to 2 for the one of higher frequency and 1 to 0 for the one of lower frequency. No line is observed as due to the rotational transition 0 to 1, though one might well be expected. If $\frac{1}{2}$ quantum of angular momentum is assigned to the lowest steady state of molecular rotation instead of a 0 quantum, then the two lines +1 and —1 are due to the rotational transitions $\frac{1}{2}$ to $\frac{3}{2}$ and to $\frac{3}{2}$ to $\frac{1}{2}$. The only rotational transition which would give a line between these two would be a transition $\frac{1}{2}$ to $-\frac{1}{2}$ indicating a reversal in sign of the minimum angular velocity. Such a line is not to be expected. The absence of a line, then, between +1 and —1 in all the bands of the halogen hydrides, and presumably also for methane, is evidence in favor of the $\frac{1}{2}$ quantum number for indicating stationary rotational states.

A second evidence is furnished by the results of applying strong electric fiields to the absorbing gas. Hettner has shown that rotating polar molecules would acquire precessional motions when in an elec-

tric field. These effects are so nearly equal in adjacent stationary states that when transitions between these states occur the resulting effects, which are difference effects, are second order effects and are not observable. But with the line —1 of the HCl fundamental, which corresponds to the transition 1 to 0, these effects do not appear as difference effects, since the state 0 means zero angular momentum, and is a state therefore unaffected by the field. The entire effect of the field on the initial state 1, therefore, remains and results in resolving this line in two components, both of which are so far displaced toward the long wave-length end of the band as to be readily observable if the effect exists.

Should, however, the lowest rotational state be characterized by a ½ quantum of angular momentum, then all the lines can only show difference effects and the phenomenon will be without the range of observation. There is thus apparently an opportunity here to test this question of integral and half quantum numbers. Barker has carried out this experimental work and finds no measurable shift of the line —1. His results confirm, therefore, the use of half quantum numbers.[12]

This descriptive treatment of the results of work on the fine structure of the near-infra-red absorption bands accounts for the most prominent features of the observed results. For a more rigorous treatment the original papers bearing upon this problem should be consulted. It can not be said, however, that the problem of the molecular structure of simple molecules has been solved in the sense that the problems of the hydrogen atom and ionized helium have been solved. Rather the situation is more analogous to that of the heavier atoms, where the solutions are qualitative rather than quantitative. The most definite results are the determinations of the moments of inertia from which it is possible in the case of the halogen hydrides to compute very accurately the distances separating the atoms.

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UNIVERSITY OF MICHIGAN.

[12] Barker, *Astrophysical Journal*, Nov. or Dec. Number, 1923.

MINUTES.

MINUTES.

Stated Meeting, January 5, 1923.

WILLIAM B. SCOTT, Sc.D., LL.D., President, in the Chair.

Dr. George W. Norris, a recently elected member, subscribed the Laws and was admitted into the Society.

The decease was announced of Friedrich Delitzsch, Ph.D., at Langenschwalbach, Germany, on December 23, 1922, æt. 72.

In commemoration of the Centenary of Louis Pasteur, Dr. Lawrence J. Henderson, of Harvard University, delivered an address on "The Life and Services of Louis Pasteur, a Member of this Society, 1885–1895." M. Burnet, Director of the Pasteur Laboratory at Tunis, made some interesting remarks.

Stated Meeting, February 2, 1923.

WILLIAM B. SCOTT, Sc.D., LL.D., President, in the Chair.

The decease was announced of Mr. Clarence S. Bement at Philadelphia, on January 27, 1923, æt. 80.

David H. Weinrich, Ph.D., of the University of Pennsylvania, read a paper entitled, "Some Protozoan Parasites of Man and Mice," which was discussed by President Scott and Dr. Weinrich.

Stated Meeting, March 2, 1923.

WILLIAM B. SCOTT, Sc.D., LL.D., President, in the Chair.

The decease was announced of the following members:

Edward Emerson Barnard, Sc.D., at Williams Bay, Wisconsin, on February 6, 1923, æt. 66.

Hon. Charlemagne Tower, LL.D., at Philadelphia, on February 24, 1923, æt. 74.

Dr. Harlow Shapley, Director of Harvard College Observatory, read a paper entitled "Stars in Science Progress," which was discussed by Professor Miller and Dr. Goodspeed.

Adjourned Stated Meeting, April 6, 1923.

William B. Scott, Sc.D., LL.D., President, in the Chair.

The decease of the following members was announced:

James Dewar, LL.D., at Cambridge, England, on March 27, 1923, æt. 80.

Edward W. Morley, A.M., LL.D., at West Hartford, Connecticut, February 24, 1923, æt. 85.

Joannes Diderik van der Waals, Ph.D., at Amsterdam, Holland, on March 8, 1923, æt. 85.

The Committee on Nominations made its report.

Special Meeting, April 10, 1923.

William B. Scott, Sc.D., LL.D., President, in the Chair.

Pursuant to the call of the President a Special Meeting was held for the award of the John Scott Medals and Premiums by the City of Philadelphia, through its Board of City Trusts, to the following:

Sir Joseph John Thomson, O.M., F.R.S., Master of Trinity College, Cambridge, for his researches on the physics of the electron.

Francis William Aston, D.Sc., F.R.S., of Trinity College, Cambridge, for his development of the mass-spectrograph and his studies of isotopes.

C. Eijkman, M.D., of the University of Utrecht, for his researches on dietary diseases.

Arthur Louis Day, Ph.D., Sc.D., Director of the Geophysical Laboratory of the Carnegie Institution of Washington, for his researches on optical glass.

Stated General Meeting, April 19, 20, and 21, 1923.

Thursday Afternoon, April 19.

Hampton L. Carson, M.A., LL.D., Vice-President, in the Chair.

Dr. Charles H. Haskins, a recently elected member, subscribed the Laws and was admitted into the Society.

The following papers were read:

"Prehistoric Misnomers," by Edwin Swift Balch, of Philadelphia.

"The Place of Spain in the History of Medieval Science," by Charles H. Haskins, A.M., Ph.D., Litt.D., LL.D., Gurney Professor of History and Political Science, Harvard University.

"Some Admiralty Cases Relative to British and American Commerce," by William E. Lingelbach, B.A., Ph.D., Professor of Modern European History, University of Pennsylvania, which was discussed by Messrs. Carson and Rawle.

"Methods and Results of Beach Reclamation on Alluvial Coasts," by Lewis M. Haupt, A.M., Sc.D., LL.D., of Philadelphia.

Friday, April 20.

Executive Session, 10 o'clock.

WILLIAM B. SCOTT, Sc.D., LL.D., President, in the Chair.

Benjamin M. Duggar, Robert DeCourcy Ward, and Henry S. Washington, recently elected members, subscribed the Laws and were admitted into the Society.

The President made his annual address.

The Proceedings of the Council were submitted, with the recommendation of fifteen nominees for election this year.

The Report of the Treasurer, of the Audit Committee, and of the Finance Committee were presented, with the latter's recommendation of appropriations for the year 1924, which were unanimously voted.

Morning Session, 10:30 o'clock.

WILLIAM B. SCOTT, Sc.D., LL.D., President, in the Chair.

The following papers were read:

"The New Millionth Map of Hispanic America," by Isaiah Bowman, B.S., Ph.D., Director of the American Geographical Society, which was discussed by Prof. Scott.

"Description of the Yale Automatic Zenith Camera," by Frank

Schlesinger, B.S., M.A., Professor of Astronomy and Director of the Yale University Observatory, and J. H. Oort, Research Assistant.

"Some Applications of Heaviside's Operational Methods," by E. P. Adams, M.S., Ph.D., Professor of Physics, Princeton University, which was discussed by Prof. Kennelly.

"Some Results Obtained by the Crocker Eclipse Expeditions from the Lick Observatory," by W. W. Campbell, Sc.D., LL.D., of the Lick Observatory, which was discussed by Professors Miller and Russell.

"Discussion of a Kinetic Theory of Gravitation, II, and Some New Experiments in Gravitation, Third Paper," by Charles F. Brush, Ph.D., Sc.D., LL.D., of Cleveland.

"Crucial Proof of the Transmutation of Atoms in the Wichita Meteorite."

"Discovery of the Element of Atomic Number 72," by Monroe B. Snyder, Director Emeritus of the Philadelphia Observatory.

"The Chemical Analysis of Minerals," by Henry S. Washington, A.M., Ph.D., Geophysical Laboratory, Washington, which was discussed by Professors Hobbs and Scott.

Afternoon Session, 2 o'clock.

William B. Scott, Sc.D., LL.D., President, in the Chair.

The following papers were read:

"Infra-red Spectroscopy," by Harrison M. Randall, Ph.D., Professor of Physics and Director of the Physical Laboratory, University of Michigan.

"Utilization of Surplus Explosives and Explosives' Wastes," by Charles E. Munroe, Ph.D., LL.D., Professor Emeritus of Chemistry, George Washington University, and Spencer P. Howell, which was discussed by Dr. Washington.

"The Explorations of the American Museum of Natural History in China and Mongolia," by Henry Fairfield Osborn, Sc.D., Ph.D., LL.D., Research Professor of Zoology, Colum-

bia University, and President of the American Museum of Natural History, New York City, which was discussed by Professor Scott.

"The Rate of Movement in Vertical Earth Adjustments Connected with the Growth of Mountains," by William H. Hobbs, A.M., Ph.D., Director of the Geological Laboratory, University of Michigan, which was discussed by Professor Scott.

"Contact Metamorphism in the Western Adirondacks," by William M. Agar, B.S., Princeton University. (Introduced by Professor Scott.)

"The Stratigraphy of the White River Beds of South Dakota," by H. R. Wanless, of Princeton. (Introduced by Professor Scott.)

"'Indian Summer' as a Characteristic Weather Type of the Eastern United States," by Robert de C. Ward, A.M., Professor of Climatology, Harvard University.

"Some Recent Experiments on the Physiological Action of Germanium Dioxide," by John H. Müller, Ph.D., Professor of Chemistry, University of Pennsylvania, which was discussed by Professors Kennelly, Scott, and Ward. (Introduced by Dr. Keller.)

"The Significance of the Gall Bladder," by Philip McMaster, M.D., of the Rockefeller Institute of New York. (Introduced by Dr. Abbott.)

"The Significance of the Histological Lesions of Rheumatic Fever," by Homer F. Swift, M.D., of the Hospital of Rockefeller Institute, New York. (Introduced by Dr. Abbott.)

"Methods of Immunizing Cattle to Rinderpest," by Edward L. Bliss, M.D., of Shaowu, China. (Introduced by Mr. Harold Goodwin.)

The Friday evening Lecture was given by Dr. Henry Norris Russell, of Princeton, who spoke on "Stars and Atoms," illustrated by lantern slides.

Saturday, April 21.

Executive Session, 10 o'clock.

William B. Scott, Sc.D., LL.D., President, in the Chair.

Pending nominations for Officers and Members were read and the Society proceeded to an election. The Tellers subsequently reported that the following had been elected:

President.

William B. Scott.

Vice-Presidents.

Hampton L. Carson,
Henry Fairfield Osborn,
W. W. Campbell.

Secretaries.

Arthur W. Goodspeed,
Harry F. Keller,
John A. Miller.

Curator.

William P. Wilson.

Treasurer.

Eli Kirk Price.

Councillors.

(To serve for 3 years.)

John C. Merriam,
James H. Breasted,
Ambrose Swasey,
Henry G. Bryant.

Members.

Frank Aydelotte, A.M., Litt.D., Swarthmore, Pa.
Edward Asabel Birge, Ph.D., Sc.D., LL.D., Madison, Wis.
Isaiah Bowman, Ph.D., New York.
Carl Darling Buck, Ph.D., Litt.D., Chicago.
Karl T. Compton, Ph.D., Princeton.
Herbert Ernest Gregory, Ph.D., New Haven.
Charles Downer Hazen, Ph.D., Litt.D., New York.
Phoebus A. Levene, M.D., New York.
George Perkins Merrill, Ph.D., Washington.
Samuel Alfred Mitchell, Ph.D., Charlottesville.
Richard Bishop Moore, D.Sc., Washington.
William John Sinclair, Ph.D., Princeton.
Vilhjalmur Stefansson, New York.
Rodney H. True, Ph.D., Philadelphia.
Thomas Wayland Vaughan, Ph.D., Washington.

Morning Session, 10 o'clock.

William B. Scott, Sc.D., LL.D., President, in the Chair.

The following papers were read:

"Physical Aspects of the Recent Analysis of the Earth's Magnetic Field," by Louis A. Bauer, C.E., M.S., Ph.D., D.Sc., Director, Dept. of Terrestrial Magnetism, Carnegie Institution of Washington.

"Some Effects of the Removal of the Thyroid Apparatus on the Growth of the Nervous System," by F. S. Hammett, Ph.D., Asst. Professor of Biochemistry, Wistar Institute, which was discussed by Professors Kennelly, Osborn, and Hammett. (Introduced by Dr. Donaldson.)

"The Mechanism of the Biological Effect of Rays," by W. T. Bovie, Ph.D., Research Fellow, Cancer Commission, and Asst. Professor of Biophysics, Harvard University (introduced by Dr. McClung), which was discussed by Professors Osborn and Conklin.

"The Origin and Distribution of the Doradidæ, a South American Family of Catfishes," by C. H. Eigenmann, Ph.D., Dean of the Graduate School and Professor of Zoölogy, University of Indiana.

"Permeability and Increase of Volume of Contents of Living and Artificial Cells," by D. T. MacDougall, A.M., Ph.D., LL.D., Director of the Dept. of Botanical Research of the Carnegie Institution, Tucson, Arizona, which was discussed by Professor Scott.

"Indications Respecting the Nature of the Infective Particles in the Mosaic Disease of Tobacco," by B. M. Duggar, Ph.D., Research Professor, Missouri Botanical Garden, which was discussed by Professors Bovie and Duggar.

"Experimental Production of Mutant Types in the Jimson Weed," by Albert F. Blakeslee, Ph.D., Department of Genetics, Carnegie Institution of Washington. (Introduced by Dr. Shull.)

"Sterile and Fertile Species Hybrids in Shepherd's Purse," by George H. Shull, Ph.D., Professor of Botany and Genetics, Princeton University.

Afternoon Session, 2 o'clock.

Henry Fairfield Osborn, Ph.D., LL.D., Vice-President, in the Chair.

The following papers were read:

"Hebe and Ganymede," by Paul Haupt, Ph.D., LL.D., Professor of Semitic Languages, Johns Hopkins University.

Symposium on "The Inheritance of Acquired Characters."

"Historical Sketch," by William B. Scott, Sc.D., LL.D., Professor of Geology, Princeton University.

"Germ Cell and Serological Influences," by M. F. Guyer, Ph.D., Professor of Geology, University of Wisconsin, which was discussed by Professors Conklin and Guyer. (Introduced by Dr. McClung.)

"Are the Effects of Long Continued Rotation Inherited?" by J. A. Detlefsen, Sc.D., Professor of Genetics, Wistar Institute, Philadelphia. (Introduced by Dr. Greenman.)

"Modifications of the Albino Rat, following Treatment with Alcohol Fumes and X-Rays; and the Problem of Their Inheritance," by Frank B. Hanson, Ph.D., Professor of Zoölogy, Washington University, St. Louis, Mo. (Introduced by Dr. McClung.)

"Chemical and Physical Effects on Germ Cells and the Transmission of Modifications," by Charles R. Stockard, Ph.D., Sc.D., Professor of Anatomy, Cornell University. (Introduced by Dr. Donaldson.)

The Symposium was discussed by Professor Scott.

Stated Meeting, November 2, 1923.

William B. Scott, Sc.D., LL.D., President, in the Chair.

Dr. Frank Aydelotte and Dr. Richard B. Moore, newly elected members, subscribed the Laws and were admitted into the Society.

Acceptances of membership were received from Doctors Frank Aydelotte, E. A. Birge, Isaiah Bowman, Carl D. Buck, Karl T. Compton, Herbert E. Gregory, Charles Downer Hazen, P. A. Levene, George F. Merrill, Samuel A. Mitchell, Richard B. Moore, William J. Sinclair, Vilhjalmur Stefansson, Rodney H. True, and T. Wayland Vaughan.

The Secretaries announced the receipt of $436.87, the Society's share in the distribution of the bequest of the late Martin G. Boyé; it was voted that this amount be added to the principal of the previous gift by Professor Boyé, the income of which is used for the purchase of books on chemistry.

Decease was announced of the following members:

George L. Goodale, A.B., M.D., LL.D., at Cambridge, Mass., on April 12, 1923. Aet. 84.

Raphael Pumpelly, D.Sc., on August 10, 1923. Aet. 86.

Charles D. Sigsbee, U. S. N., at New York, on July 19, 1923. Aet. 77.

Stephen Paschall Sharples, B.S., M.S., at Deer Island, Maine, on August 20, 1923. Aet. 81.

Charles P. Steinmetz, Ph.D., at Schenectady, N. Y., on October 26, 1923. Aet. 58.

Hon. Mayer Sulzberger, M.A., LL.D., D.H.L., at Philadelphia, on April 20, 1923. Aet. 80.

William Roscoe Thayer, A.M., LL.D., Litt.D., L.H.D., at Cambridge, Mass., on September 7, 1923. Aet. 64.

Arthur Gordon Webster, Ph.D., Sc.D., at Worcester, Mass., on May 15, 1923. Aet. 60.

Dr. Richard B. Moore, late Chief Chemist of the U. S. Bureau of Mines, read a paper on "Helium," illustrated by lantern slides.

Stated Meeting, December 7, 1923.

William B. Scott, Sc.D., LL.D., President, in the Chair.

The decease was announced of James Cheston Morris, M.D., at West Chester, Pa., on November 29, 1923. Aet. 92.

Dr. Frank Aydelotte, President of Swarthmore College, read a paper on "Anglo-American Educational Relations."

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